Application Brief

Enhancing EV Powertrain Efficiency: Optimizing Motor Control and Battery Performance With TMS320F28P55x MCUs

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Introduction

The fast growth of the 2-wheeler and 3-wheeler electric vehicle (EV) platform, particularly in India and Southeast Asia, presents new design challenges. These design challenges include increasing EV range, reducing end-product cost, and delivering high-performance powertrains for consumers. Efficient traction inverter and battery management system (BMS) solutions are essential for optimizing performance, cost, and range. The primary focus of this article is to examine how automotive TMS320F28P55x microcontrollers (MCUs) help manufacturers address these design challenges and meet evolving market demands. The high real-time performance, advanced analog and control capabilities of these MCUs, combined with TI's open software ecosystem, reference designs, and product support empower manufacturers to achieve their design goals and meet production timelines for traction inverter and BMS applications.

Enhancing Powertrain Efficiency for Extended Range and Increased Performance

Effective Traction Inverter Solutions for Motor Control

The power efficiency of traction inverter systems has the biggest impact on an EV's range. In these applications, it is important to utilize MCUs that include accelerators to assist the CPU for mathematical operations, enhancing efficiency and accuracy in motor control. This directly benefits traction inverter systems by enabling a more efficient use of power within the EV powertrain. The TMS320F28P55x MCUs feature several CPU accelerators such as the Floating-Point Unit (FPU), Trigonometric Math Unit (TMU), and the Control Law Accelerator (CLA).

An FPU simplifies the porting process of control algorithms that rely on floating-point math, significantly reducing development effort compared to MCUs based on fixed-point math or without an FPU. Additionally, the FPU enables the MCU to support hardware that uses IEEE-754 single-precision floating-point format operations by providing extra floating-point registers and instructions. Complex mathematical operations such as FFT and square root operations take a significantly reduced number of cycles to complete using the FPU; by more than 2x compared to fixed-point math MCU solutions (see Table 1).

Table 1. FPU Performance Improvements

Function	Type	FPU Cycles	FPU64 Cycles	Fixed Cycles	Improvements/Comments
Complex FFT	512 pt 1024 pt	24243 53219	43935 98683	63192 141037	2.61x (FPU) / 1.44x (FPU64) vs fixed point 2.65x (FPU) / 1.43x (FPU64) vs fixed point
Real FFT	512 pt 1024 pt	13670 30352	20219 45476	34513 76262	2.52x (FPU) / 1.71x (FPU64) vs fixed point 2.51x (FPU) / 1.68x (FPU64) vs fixed point
Square Root	Compiler intrinsic	22	22	64	2.91x (FPU/FPU64) vs fixed point - Both modes uses 32-bit floating-point arguments
Finite Impulse Response (FIR)	64 pt	119	280	111	0.93x (FPU) / 0.40x (FPU64) vs fixed point - FIR algorithms using circular addressing mode

The TMU benefits both the C28x CPU and the FPU, by further enhancing the instruction set of the CPU. Table 2 includes the list of operations made available by the TMU. Having these instruction capabilities significantly reduces cycle count for commonly used control applications that are heavy on trigonometric calculations such as park and inverse park transforms, space vector generation, and FFT magnitude and phase calculations.

Table 2. TMU Supported Instructions

Operation	C Equivalent Operation
Multiply by 2*pi	a = b * 2pi
Divide by 2*pi	a = b/2pi
Divide	a = b/c
Square Root	a = sqrt(b)
Sin per Unit	a = sin(b*2pi)
Cos per Unit	a = cos(b*2pi)
Arc Tangent per Unit	a = atan(b)/2pi
Arc Tangent 2 and Quadrant Operation	Operation to assist in calculating ATANPU2
Logarithm	a = LOG_2(b)
Inverse Exponent	a = $2^{-\|b\|}$

The CLA works in parallel with the C28x CPU and the aforementioned accelerators, reducing the bandwidth for the CPU by managing low-level control loops. With access to various different peripherals on the TMS320F28P55x MCU, it enables fast interrupt responses, minimizing MCU interrupt latency and control loop delays. As seen in Figure 1, the CLA helps pipeline several different commands sent to the CPU and thus helps facilitate a tighter control loop. All of these hardware accelerators support the MCU's core responsibilities and efficiency within the HEV/EV powertrain's operations, enabling increased range for the EV.

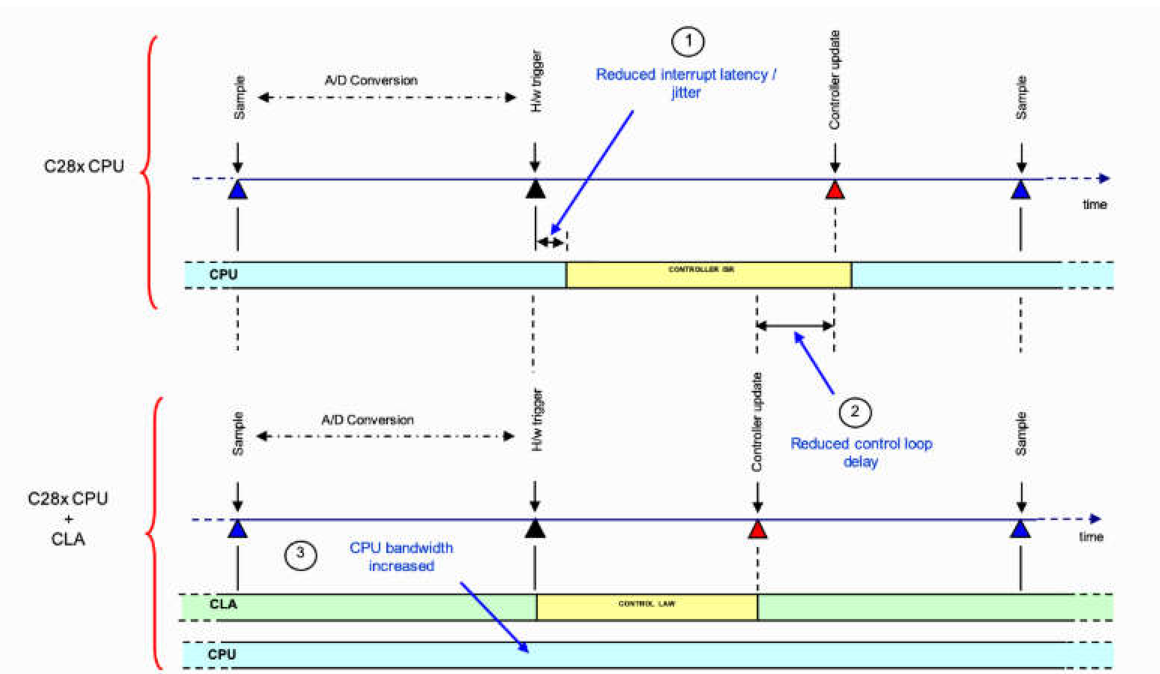

Figure 1. Benefits of the CLA

These devices are rich with tightly coupled sensing peripherals, high processing speeds, and fast actuation enabling real-time, low-latency control. Additionally, high-speed ADCs and enhanced PWM (ePWM) modules make these devices ideal for high-performance motor control and digital power applications in the automotive market. The TMS320F28P55x devices also come integrated with a comparator subsystem (CMPSS) and programmable gain amplifiers (PGAs) to reduce BOM costs as well, adding to the end-customer benefit of utilizing these MCUs.

Optimizing Battery Pack Use

A critical design challenge in the EV market is to improve the range of EVs. The BMS plays an important role in EV range because it needs to supply power for the EV powertrain in the most efficient manner possible. As design requirements increase over time, improving the BMS software becomes more paramount. In turn, designers are looking for MCUs that feature hardware to help increase the performance and capabilities of the BMS software. Specific to the TMS320F28P55x MCUs is an integrated neural-network processing unit (NNPU), which accelerates certain machine learning operations. In the context of the BMS, this form of edge AI benefits machine-learning-based State of Charge (SoC) and State of Health (SoH) algorithms. Furthermore, a growing interest in the BMS is to utilize Electrochemical Impedance Spectroscopy (EIS) because of the detailed insights into internal cell parameters. This information in turn can be used to provide a significantly more accurate SoC and SoH reading for the battery pack, meaning the range measurement for an EV becomes more precise. When Remaining Useful Life (RUL), SoC, and SoH are all maintained accurately, the EV is more likely to operate near its original maximum range.

X-in-1 Integration Enabling Compact, Cost-Effective Designs

X-in-1 integration is a system design technique where a single MCU controls multiple components of the EV powertrain and is growing in popularity. X-in-1 integration significantly reduces cost for the designers of these systems since they use less materials to achieve the same powertrain functionality. Addressing this trend is paramount as this is projected to become a market-wide strategy, especially in 2-wheeler and 3-wheeler EVs applications where saving on space and costs is a must. The aforementioned CLA featured on the TSM320F28P55x MCU can essentially operate as less-powerful, but additional CPU for the MCU. This enables the device to support more bandwidth-heavy control algorithms, without sacrificing performance. Having this feature on an MCU has the potential to significantly improve costs, simplify manufacturing, and consolidate software functionality for ease of over-the-air (OTA) updates. Though X-in-1 integration demands more bandwidth from the MCU, it minimizes both the size and weight of the EV powertrain.

Conclusion

Designing 2-wheeler and 3-wheeler platforms that are equipped with long-range, cost-effective, and high-performance powertrain systems is paramount as the platform continues to grow. As manufacturers migrate to auto-qualified devices for 2-wheeler and 3-wheeler powertrain applications, the demand for safe, reliable, and high-performance solutions continues to increase as well. TI also provides a resourceful support ecosystem for the 2-wheeler and 3-wheeler EV market customers. This ecosystem includes reference designs such as the TIDM-02017, Mathworks model-based design for simulation and code generation, and close customer support via C2000 Microcontrollers Forum and other platforms. With the TMS320F28P55x MCU's scalable offerings, these devices help enable the next generation of high-performance, extended range, and cost-friendly BMS and traction inverters. The TMS320F28P55x MCUs combined with a diverse hardware and software support system equip manufacturers with the quickest, high-performance solution to the 2-wheeler and 3-wheeler automotive market.

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