WHITE PAPER

Texas Instruments

Enabling Greener Embedded Control Systems with Floating-Point DSCs

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Executive summary

Digital signal controllers (DSCs) offer the most advanced form of single-chip control processing available for high-end embedded systems. The new TMS320F283x DSCs add a floating-point architecture to Texas Instruments' proven DSC platform, bringing higher performance and simpler software development to embedded applications such as motor and motion control, automotive radar systems and renewable energy generation from sources such as solar arrays and windmills. In addition to saving processing cycles and program memory, the floating-point architecture enables more computationally advanced algorithms that can help save energy while extending system capabilities. Floating-point programming is faster than fixed-point, and system-on-a-chip (SoC) integration keeps board space, component counts and overall system costs in line. This paper discusses what the floating-point architecture is and details the advantages that TI's new F283x DSCs bring to sophisticated, energy-saving control applications.

Efficient control saves energy

The need to conserve energy affects every type of equipment we use, including some that are not obvious to consumers. Industrial motors, for instance, consume huge amounts of power—as much as two-thirds of all the electricity used by industry, according to the ABB Group, a supplier of power and automation technology. Most motors could be made to run more efficiently with variable-speed drives, but only one motor in 20 has the digital control electronics that enable this feature. Even so, every year variable-speed motors manage to save the output of 10 power plants—some 68 million tons of greenhouse gases—compared with their fixed-speed equivalents. Clearly, advanced motor control offers a great opportunity for saving energy and benefiting the environment.

Another "green" opportunity for control is in renewable energy sources such as solar panels and wind turbines. Like motors, these energy gatherers and other sources such as fuel cells need advanced digital control for efficiency. Control is necessary in order to convert the raw voltage from panels or turbines in real time to the appropriate voltage for battery storage or running appliances. In addition, variable levels of sunlight and wind require sophisticated algorithms to help maximize the power output at all times; and since many renewable energy systems tie into the electrical grid, real-time control is needed for protection as well.

Digital control can help protect people as well as systems. For instance, radar systems are being introduced into automobiles to help drivers avoid other vehicles in the blind spot during a lane change, or when using cruise control on the highway. While these sensing applications do not need control electronics to deal with large quantities of power, in operation they still require the same real-time digital control that benefits motors and renewable energy sources. As embedded systems continue to undertake more sophisticated tasks, whether to conserve power or to enable new capabilities such as vehicle guidance, they demand ever greater performance from control processors. The TMS320F283x DSCs provide this high level of performance.

Industry's first floating-point DSCs

For the past decade, Texas Instruments has been supplying high performance and system-on-a-chip (SOC) integration for embedded control applications. TI's TMS320C2000™ DSCs have consistently been industry leaders in control performance, and on-chip peripherals such as high-speed analog-to-digital converters (ADCs) and high-resolution pulse-width-modulated (PWM) outputs have helped reduce system space and costs. Extensive software and tools support from TI and its DSP Developer Network help simplify development and give programming a "look and feel" that is familiar for those who are accustomed to working with general-purpose microcontrollers. All of these factors have enabled TI customers to build innovative control applications that save power and lower system costs.

The F283x DSCs build on this proven base with the addition of a floating-point architecture that increases performance, simplifies programming, and enables more sophisticated algorithms for advanced capabilities. This 32-bit DSC family operates at speeds up to 150 megahertz (MHz) and can perform as many as 300 million floating-point operations per second (MFLOPS). The floating-point architecture boosts performance by 50 percent or more over TI's TMS320F28x fixed-point DSCs, the previous leaders in performance. F283x DSCs build on the F28x platform, bringing all the advantages of integration inherent in the earlier-generation devices and ensuring complete software compatibility. In addition, F283x devices introduce, for the first time in a DSC architecture, a six-channel on-chip direct memory access (DMA) controller that offloads data transfer management from the processing core, and software innovations that make it easier to develop both floating- and fixed-point code from the same source.

The initial release of the F283x products includes three devices with different memory options. Figure 1 shows the features of one of these devices, the F28335, which integrates

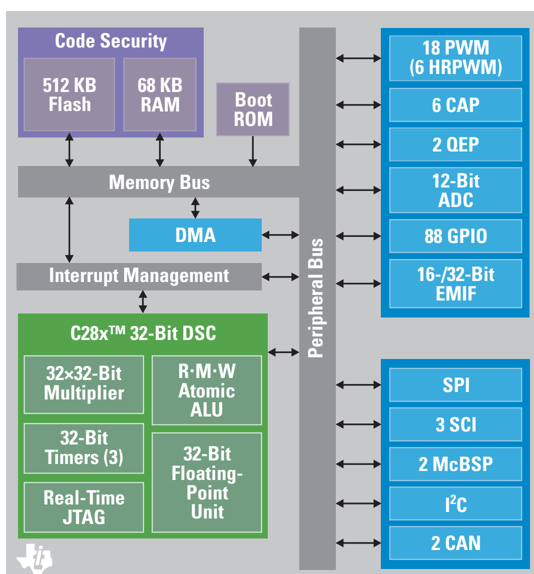

Figure 1. TMS320F28335 DSC architecture (block diagram)

512 KBytes of Flash memory for code and 68 KBytes of data RAM. On-chip peripherals include an extremely fast 12-bit ADC that handles up to 16 channels, a memory interface that is configurable for either 16 or 32 bits, and 18 PWM outputs that include six high-speed PWMs for controlling up to three three-phase motors. A variety of interfaces support communication with external devices, including other DSCs and microcontrollers through the CAN bus. Support includes the Code Composer Studio™ integrated development environment (IDE), eZdsp™ development tool, IQMath "virtual" floating-point software library, and software libraries for specific applications. All of these features make the F283x DSCs the most advanced controllers available, and the best suited for energy savings and new capabilities in motors, renewable energy, and automotive radar applications.

TI has also recently introduced the new fixed-point F282x DSCs, which are 100 percent code-compatible with F283x devices and can be programmed using the same development tools. The F282x controllers are completely pin-to-pin compatible with the F283x series, which will enable developers to create a control system using floating-point operations for greater accuracy and rapid programming, then recompile the same source code to be used on a fixed-point device for cost efficiency without re-designing any hardware. Further information on TI's F283x DSC generation can be found at **www.ti.com/f2833x**.

Floating-point math

Most of the advantages of the F283x DSC generation derive from its numeric format, which simplifies programming, saves execution cycles and reduces code size. The fixed-point format used in other DSCs and in traditional fixed-point DSPs represents only integers (positive and negative numbers without a decimal point), so that additional notation is necessary to deal with fractions. By contrast, the F283x floating-point format represents real numbers (those with decimals) over a much greater range. The internal representation of decimals and the wide numeric range means that scaling operations such as multiplication, division and the trigonometric functions, which are quite common in control algorithms, can be more efficiently carried out using floating-point values.

Consider the 32-bit fixed-point F28x architecture, which represents integer values ranging from 2^{-31} to 2^{31}. (One bit of the word is reserved as a ± sign.) While this is an extensive range, it can be used up quickly when the system has to perform numerous scaling operations, causing numbers to grow beyond 32 bits, thus overflowing registers. The program can deal with this problem, known as saturation, by rounding or truncating the numbers, in which case it sacrifices precision. Alternatively, the program can slice the long numbers into shorter ones that it operates on piece by piece, 32 bits at a time. In the latter case, full precision can be retained, but performance suffers since the processor is busy moving and storing the pieces. Also, program size grows with the additional instructions required.

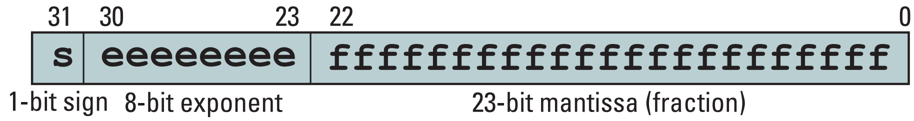

Figure 2. TMS320F283x 32-bit floating-point word

Here the floating-point architecture shows its worth. As Figure 2 illustrates, eight of the 32 bits in the F283x word are used as an exponent, leaving 23 bits for the mantissa (the number being raised to the power of the exponent) and one bit for the sign. Although there is no sign bit for the exponent, a normalizing bias is added to the stored exponent in operation, yielding a range of exponents that are both negative and positive in value. The numeric values that can be stored in this 32-bit floating-point word, then, have a normalized range from $\pm\sim1.7^{-38}$ to $\pm\sim3.4^{38}$—considerably greater than the 32-bit fixed-point range. Since the negative exponents represent fractions, this range extends from extremely small values to extremely large ones. With such a wide range, there is little likelihood of saturation, so the program avoids the dilemma of either sacrificing precision through rounding or truncating, or sacrificing performance and storage by using additional cycles and instructions to operate on separate pieces of long numbers.

Performance enhancement

The operations listed in Table 1 illustrate how much advantage the floating-point architecture brings to DSC performance. The first column lists four arithmetic and trigonometric functions and two algorithms (Fast Fourier Transform and infinite impulse response) that are commonly used in control systems. The second column shows the cycles required on a TMS320C2812 DSC to perform the operation, and the third shows the cycles required on an F283x running at the same frequency. The final column divides the second column by the third to show relative performance. The floating-point device performs all the math operations listed two to three times as fast as the fixed-point device. The FFT is in this range as well, and the IIR slightly slower but still much faster than with fixed-point math.

Table 1. Fixed- Versus Floating-Point Performance Benchmarks

Operation/ Algorithm	TMS320C28x™ 32-Bit (Fixed)*	F283xx Optimized Assembly (Floating)*	Fixed/Floating Performance Ratio
Division	70	24	2.92
Square root	60	27	2.56
Sine, cosine	92	44	2.09
Atan2	118	53	2.33
FFT complex (256)	~27000	~11000	2.45
IIR cascaded	14 cycles/filter	8 cycles/filter	1.75

** C2812 equivalent cycles*

In general, control algorithms benefit more than signal-processing algorithms because control code performs more basic math operations, requiring fixed-point scaling and saturation manipulations. Even so, cycle counts are much lower across the board for the floating-point architecture, with an average performance enhancement of about 50 percent for all signal-processing benchmarks run. Code compression is similarly effective. As an example, in a square root operation, 66 words are needed using fixed-point math, but only 42 words using floating-point.

In application, these and other benchmarks translate into a number of tangible advantages. Finer-grained, multidimensional control is possible for robotics and computer numeric control (CNC) machines. Servo motor drives become more power efficient, with the capability of implementing power line control (PLC) and other advanced algorithms. Solar and wind-powered inverters and uninterruptible power supplies see improved power conversion efficiency, helping bring down the cost per kilowatt produced, and control of different configurations of panel arrays or turbines is possible. Automobiles offer their drivers better object detection for lane departure warning and blind spot detection, plus longer range detection for adaptive cruise control. These benefits and others are enabled by the higher performance inherent in the F283x DSC's floating-point architecture.

Software development advantages

The floating-point format also simplifies writing and debugging code. Floating-point numeric representations are more natural to mathematical operations than fixed-point and are thus supported more readily in high-level languages. Once the code has been written and debugged for validation using a PC-based IDE, it can be directly ported to the floating-point DSC for further testing and ultimate production. By contrast, the method of developing code for a fixed-point controller has been to write and debug the program on a PC for validation, then tediously rewrite the code using the more stringent fixed-point representations of the hardware. This process adds significantly to the development cycle, and once the transition has been made there is no going back. Ordinarily, separate fixed- and floating-point versions of the code have to be maintained, bringing a risk that discrepancies can creep in. Since F283x controllers require only the development of floating-point code, they simplify this process, save time and promote software reliability.

In addition, F283x devices are fully compatible with earlier F28x DSCs, so that fixed-point code that has already been developed can be recompiled and run without modification. And TI's C compiler and IQMath library have been revised with the F283x introduction so that it is now easy to write, compile and update code for use by either a floating- or fixed-point device. The process works this way: a programmer creates source code using IQMath functions with the floating-point mode enabled, then compiles and debugs the code using a floating-point device. Next, if necessary, the programmer enables IQMath's fixed-point mode, then compiles and debugs on a fixed-point device. No tedious recoding is needed, and the code can be updated and recompiled as many times as necessary for both formats. To help optimize scaling and saturation during fixed-point operation, the floating-point mode enables the programmer to determine the range of values required by the algorithm, then set this range for fixed-point compiling. For the first time, floating-point code can now be written for direct use on a fixed-point DSC.

Cost constraints sometimes make it advantageous to follow the strategy of using a floating-point controller as a development platform for prototyping and early release, then changing over to a fixed-point controller for volume manufacturing. The C compiler and IQMath support this strategy by making it easy to compile the same source code either way. On the other hand, the F283x DSC offers economy to manufacturers since it is the first floating-point controller with SOC integration. The crossover point for floating- versus fixed-point costs now rises to higher volume levels, so that many advanced systems may not need to make the change in order to see savings. The higher performance and easier development of a floating-point architecture is now more affordable to a much wider range of applications, spurring the development of further innovations in embedded system control.

Innovative, affordable and green

Advanced digital control provides a way to conserve energy while extending the capabilities of electronic systems. TI's TMS320C2000™-based digital signal controllers offer the highest performance available among microcontrol units, software support that makes the devices easy to use, and system-on-chip integration that provides affordability for a wide range of embedded applications. F283x DSCs add a floating-point architecture to TI's DSC offerings, increasing performance by at least 50 percent over fixed-point devices while retaining comprehensive support and cost-efficiency. Programming becomes much easier with the floating-point architecture and tools, reducing time and trouble for developing both floating- and fixed-point code. The high performance, ease of use and affordability of F283x DSCs make these devices the optimum solutions for sophisticated control applications such as motors, renewable energy and vehicle radar sensing.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

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