WHITE PAPER

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An Introduction to the Stellaris® LM4F Family of Microcontrollers

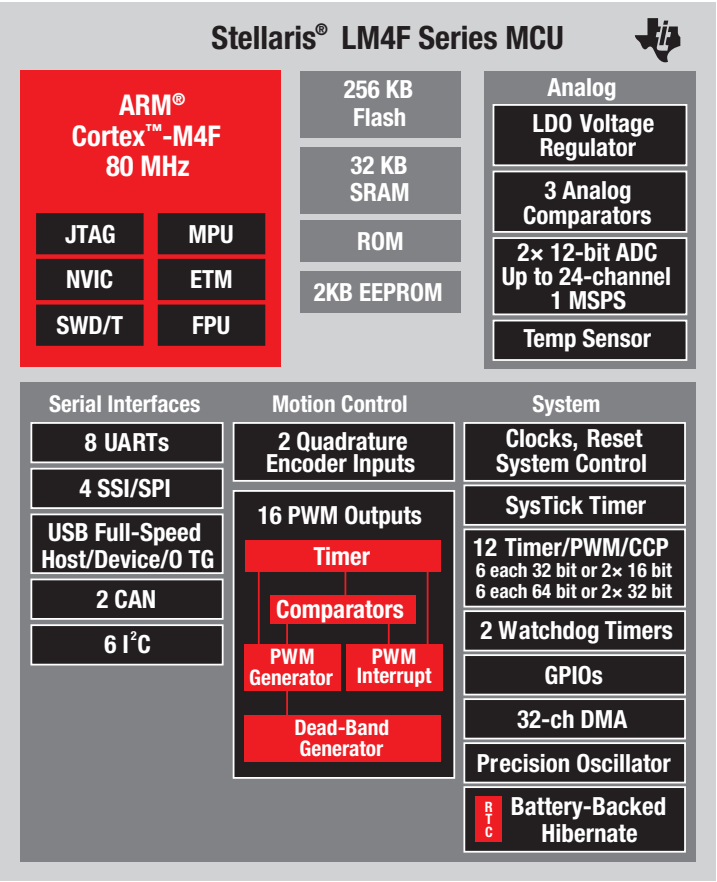
Introduction

Stellaris® microcontrollers (MCUs) were the first MCU on the market to be based on the ARM® Cortex™-M core, an architecture that has quickly become a top choice for many developers across the globe. Since its establishment, the Stellaris product line has remained true to its original goals – providing the broadest portfolio of highly connected, low cost and easy-to-use 32-bit microcontrollers. The latest Stellaris LM4F series refines the offering of MCUs, greatly improving performance and raising features to a new level of quality.

Leading analog integration, best-in-class low-power consumption and floating-point performance in next generation Stellaris ARM® Cortex™-M microcontrollers

Stellaris LM4F microcontrollers take advantage of two significant technologies: the latest ARM Cortex-M4F core and the design techniques and process technologies perfected at Texas Instruments. The result is a 32-bit microcontroller family with processing performance that is more effective per clock cycle, integrated mixed-signal circuits that are on par with traditional standalone components, flash memory with erase-write endurance that is best-in-class and power consumption that is highly competitive with other 32-bit MCUs in both active and standby modes. Such qualities will further increase the breadth of applications powered by Stellaris MCUs and enable applications that were not previously feasible.

The major features of Stellaris ARM Cortex-M4F microcontrollers are depicted in the block diagram of Figure 1. A more thorough list can be found in the product data sheets.



▲ ***Fig. 1 -*** Block diagram of TI's Stellaris LM4F series of microcontrollers.

ARM Cortex-M4F: Higher performance, still compatible

The Stellaris LM4F series makes use of the most advanced ARM architecture core for microcontrollers, the Cortex-M4F. As a 32-bit architecture, Cortex-M microcontrollers enjoy a rich instruction set with far greater flexibility than 8- or even 16-bit architectures and can operate on data that is up to 32-bits wide with ease. The long and successful history of the ARM architecture in embedded applications assures the greatest selection of third-party hardware and software support, pre-packaged off-the-shelf software like stacks and real-time operating systems (RTOSs) and experienced engineering and programming personnel for any project.

Previous Stellaris generations used the original Cortex-M3 architecture. The Thumb-2 instruction set of this earlier version of the Cortex-M core is a high-density, power-efficient instruction set suitable for a wide variety of general-purpose data processing and control operations.

The Cortex-M3 Thumb-2 instructions include arithmetic, logical, bit, branch and data movement operations found on many MCUs. It also adds more advanced operations and multiplication, bit-field manipulation, conditional prefixes and operates on 8-, 16- and 32-bits of data. The ARM Cortex-M3 has become a standard for modern 32-bit microcontrollers.

The new Cortex-M4 expands the instruction offering of the Cortex-M3 by adding digital signal processing (DSP) extensions and single instruction, multiple data (SIMD) instructions. The Stellaris LM4F series also includes the floating point option (the "F" in the Cortex-M4F) across the entire offering of LM4F products.

The DSP operations of the Stellaris LM4F series include single-cycle 32-bit or dual 16-bit multiply-accumulate (MAC) instructions and saturating arithmetic instructions. Optimized SIMD instructions can perform four 8-bit or two 16-bit arithmetic operations in a single cycle and are therefore very effective at performing arithmetic operations on large arrays of data. The hardware divide logic produces a result in between 2 and 12 clock cycles. Together, these instructions add DSP-like capability to a responsive controller core.

The single precision floating-point instructions are compliant with the IEEE 754 standard and include functions such as square root and a fused MAC that enable higher precision. Numerous data type conversions are available, speeding transitions between domains.

Besides providing a significant performance increase for math-intensive operations, floating-point support greatly simplifies the implementation and programming of floating-point routines. It is not uncommon for a customer to spend one week developing a digital filter then spend another month converting the filter to a fixed-point implementation to ensure it is both precise and stable. This development time is not required when programmers can program their filters in the native floating-point format.

Embracing Texas Instruments' integrated technologies

Now firmly embedded into Texas Instruments' microcontroller catalog, the new Stellaris microcontrollers have taken full advantage of the advances and technologies that TI has honed to excellence.

In some cases, like the mixed-signal circuits and the memory structures, specific circuits were targeted. On the other hand, an aggressive process technology has led to a reduction in power consumption across the board. In the end, the Stellaris LM4F family of devices is an accumulation of many feature enhancements and technology improvements.

Precision integrated analog

In building the Stellaris LM4F microcontrollers, special effort went into designing high-quality, high-resolution analog-to-digital converters (ADCs). The result is seen in the integrated high-resolution 12-bit ADC that samples as fast as 1 MSPS, a sample rate that supports both the full resolution and accuracy of the ADCs, unlike other MCUs that degrade the quality of the readings to achieve higher sample rates. Two of these converters are on-chip and can be fed from 24 independent inputs. To enhance precision, a differential external reference voltage can be applied to dedicated inputs.

The ADCs can generate processor interrupts based on a conversion completion as well as on a match to one of eight digital comparators. Readings from the ADCs can be queued, compared and averaged within the ADC. The on-chip micro direct memory access controller (µDMA) can feed ADC readings from the ADC FIFOs to RAM or another peripheral without waking up or distracting the ARM core.

There are also three on-chip analog comparators that can be used with a programmable internal voltage reference detect when an input analog signal has crossed a specific threshold. These three analog comparators, along with the digital comparators, remove the requirement of continuously polling incoming ADC values and free up the CPU to focus on real-time application tasks.

Motion control is just one application that can take advantage of fast, accurate ADCs, floating-point performance to run more sophisticated algorithms and on-chip comparators. The more quickly and precisely the motor driver can track the dynamics of a motor during actual operation, the less pushback resistance the generated PWMs will encounter and the more efficient the control signals will be. Less energy will be expended and the shaft will spin smoother and maintain speed or accelerate in spite of varying loads. The on-chip comparators can be used to check for fault conditions in the system requiring immediate response.

Reliable memory can be distinctive

It can be hard to get excited about memory. It is often simply taken for granted. But changing to a TI 65 nm process for the Stellaris LM4F family raises the products to a new level of reliability and integration.

Borrowing the flash technology that TI developed for use in automotive products, the Stellaris LM4F MCUs have extended memory durability by an order of magnitude beyond competition. The minimum number of times the flash memory on these MCUs can be erased and reprogrammed is as high as 100,000 cycles. For most applications, this breakthrough eliminates any concern of wearing out the memory from re-flashing for data collection, configuration parameters or program modifications.

More of the high-reliability flash is also available for customer-written code because StellarisWare® drivers are embedded in a small mask ROM on-chip. All Stellaris LM4F MCUs have the StellarisWare binaries committed in on-chip ROM, including the peripheral drivers, the in-system programming routines, utilities such as CRC (cyclic redundancy check) algorithms, and AES (advanced encryption standard) tables. These APIs (application programming interfaces) let the programmer take full advantage of these well-proven services, routines and tables, while leaving all of the flash for customer and application-specific code.

There are many other memory features on the MCUs, but one new memory type deserves special attention. The new Stellaris LM4F MCUs have 2K bytes of secure, on-chip EEPROM. EEPROM is normally used to store long-term variables that may even need to survive power outages and dead batteries. Since the implementation is interrupt-enabled, the integrated memory allows for the execution of code while writing values to nonvolatile memory (execute-while-write). The EEPROM use is architected using a built-in wear-

leveling technique that ensures each location can be modified 500,000 times. If the data was re-written 100 times a day, the EEPROM would last nearly 15 years!

Power savings extend battery life

The power requirements for embedded systems continue to be a key design parameter for consideration. Many end equipments run off a battery; therefore a long battery life can set a customer's product apart from competing systems. Even mains-powered equipment often has limitations on the power budget. As an example, many new products now draw their power solely from a USB cable, which is limited by the USB specification to a maximum of 500 mA.

The first way TI achieved best-in-class power consumption, where class is defined by the Stellaris family of devices, was by using a proprietary 65 nanometer (nm) process. This special 65 nm process lowers power consumption for the microcontroller without sacrificing the high performance available from the ARM Cortex-M4F core. The Stellaris LM4F family is the only Cortex-M microcontroller family implemented on a process as advanced as 65nm.

Stellaris LM4F MCUs also have a number of clock and power domains that can be gated as needed to manage power. When the DSP or floating-point units are not needed, for example, or if any of the peripherals will be idle, power and/or clocking to those modules can be shut down in order to optimize power consumption.

Stellaris LM4F devices provide sleep, deep-sleep and hibernate (HIB) modes to save power when minimal functionality is required. In the hibernate mode, power to the entire chip is cut off except to the HIB block, leaving the MCU in a state where it can be brought back to life when the need arises. The HIB block includes a 32 kHz oscillator circuit, a supporting real-time clock (RTC) module, a battery monitor circuit and sixteen 32-bit words of backup battery SRAM. This minimalist implementation allows the power consumption to be reduced, in hibernate (HIB) mode, to as little as 1.6 µA. The Stellaris LM4F devices can be awakened from hibernation by an RTC match, from an external signal, or from a low voltage detection circuit.

It might be minutes, hours, or even days between events that cause the device to come out of hibernation. The longer the duration and the lower the power of the hibernation state, the longer between recharges or replacement of batteries.

Additionally, the state of all GPIO lines can be saved during hibernation until the chip wakes up. Upon awakening, the chip goes through a power-on reset and starts executing instructions in a maximum of 500 µS. In full 80 MHz execution mode from flash, the Stellaris LM4F devices consume a typical 30 mA. A full description of the power modes is shown in Figure 2.

Mode → / Parameter ↓	Run Mode	Sleep Mode	Deep Sleep Mode	Hibernate (VDD3ON)	Hibernate (RTC)	Hibernate (no RTC)
I_{DD}	30 mA#	4.5 mA	600 µA*	5 µA	1.7 µA	1.6 µA
V_{DD}	3.3 V	3.3 V	3.3 V	3.3 V (for GPIO state net)	0 V	0 V
V_{BAT}	N.A.	N.A.	N.A.	3 V	3 V	3 V
System Clock	80 MHz with PLL	16 MHz no Pll	30 kHz	Off	Off	Off
Core	Powered On	Powered On	Powered On	Off	Off	Off
	Clocked	Not Clocked	Not Clocked	Not Clocked	Not Clocked	Not Clocked
Peripherals	All Off	All Off	All Off	All Off	All Off	All Off

▲ ***Fig. 2 -*** A full description of the power modes available on Stellaris LM4F devices
Specs provided are nominal, running from flash, * Preliminary, subject to change

Stellaris Cortex-M microcontrollers: The right devices for your application

With over 230 Stellaris ARM Cortex-M3 microcontrollers in production today, the Stellaris MCU portfolio provides one of the broadest offerings of ARM Cortex-M microcontrollers in the marketplace. The 40 Stellaris LM4F devices announced in 2011 are only the beginning of a much broader family of Cortex-M4F implementations.

A few key points from the Stellaris LM4F family have been highlighted: floating-point performance, the integrated analog, the integrated memory, and the low-power consumption. Many of these advantages come as a result of either integrating the new ARM Cortex-M4F core, leveraging the TI analog design expertise, or as a result from using TI's differentiated 65nm process technology.

For the future, customers can expect a roadmap that leads to higher integration, more performance, and even lower power. To evaluate the current LM4F devices, Texas Instruments offers the Stellaris EK-LM4F232 evaluation kit, priced at $149 USD, which includes all the hardware and software to get started in 10 minutes of less. This includes a demo of a data logging application that highlights the integrated 12-bit analog-to-digital converters (ADCs), power consumption, USB and the high-reliability flash.

Find out more about Stellaris LM4F MCUs, tools and software:

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Stellaris Cortex-M4F microcontrollers: **ti.com/cortexm4f**

Order your EK-LM4F232 evaluation kit: **ti.com/ek-lm4f232**

Video overview of Stellaris LM4F microcontrollers: **www.ti.com/cortexm4-v**

Make the Switch to Texas Instruments MCUs: **www.ti.com/make-the-switch**

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