MICROCONTROLLERS

Chapter 6

An Introduction to ARM Cortex M MCUs

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References:

- ARM® Cortex® M4 Cookbook – Mark Fischer – Packt publishing – 2016
- The Definitive Guide to ARM Cortex-M3 and Cortex-M4 Processors – Joseph Yiu – Newnes - 2014
- http://www.st.com/
- http://www.ti.com/
- https://www.nxp.com
- http://www.Wikipedia.com

Microcontroller vs Microproccessor

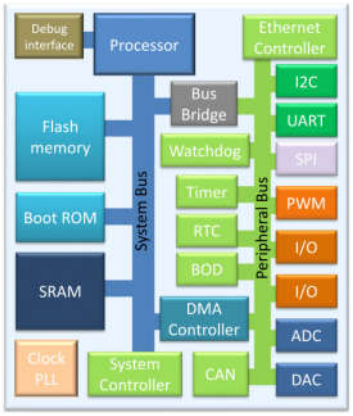
ARM® does not make microcontrollers. ARM designs processors and various components that silicon designers need and licenses these designs to various silicon design companies including microcontroller vendors. Typically we call these designs "Intellectualy Property" (IP) and the business model is called IP licensing.

In silicon) and distril units, communication interface, timers, ADC, DAC, etc.) as shown in Figure 1.2.

Although many microcontroller vendors use ARM Cortex-M processors as their choice of CPU, the memory system, memory map, peripherals, and operation characteristics (e.g., clock speed and voltage) can be completed differently from one product to another. This allows microcontroller manufacturers to add additional features in their products and differentiate their products from others on the market.

This book is focused on the Cortex-M3 and the Cortex-M4 processors. For details of the complete microcontroller system design, such as peripheral details, memory map, and I/O pin assignments, you still need to read the reference manuals provided by the microcontroller vendor.

Inside of an Microcontroller



Introduction to ARM Cortex

The Cortex®-M3 and Cortex-M4 are processors designed by ARM®. The Cortex-M3 processor was the first of the Cortex generation of processors, released by ARM in 2005 (silicon products released in 2006). The Cortex-M4 processor was released in 2010 (released products also in 2010).

The Cortex-M3 and Cortex-M4 processors use a 32-bit architecture. Internal registers in the register bank, the data path, and the bus interfaces are all 32 bits wide. The Instruction Set Architecture (ISA) in the Cortex-M processors is called the Thumb® ISA and is based on Thumb-2 Technology which supports a mixture of 16-bit and 32-bit instructions.

In general, the ARM Cortex-M processors are regarded as RISC (Reduced Instruction Set Computing) processors. Some might argue that certain characteristics of the Cortex-M3 and Cortex-M4 processors, such as the rich instruction set and mixed instruction sizes, are closer to CISC (Complex Instruction Set Computing) processors. But as processor technologies advance, the instruction sets of most RISC processors are also getting more complex, so much so that this traditional boundary between RISC and CISC processor definition can no longer be applied.

ARM vs AVR

- The AVR is a modified Harvard architecture machine, where program and data are stored in separate physical memory systems that appear in different address spaces, but having the ability to read data items from program memory using special instructions. However, it is commonly accepted that AVR stands for **A**lf and **V**egard's **R**ISC processor.Note that the use of "AVR" in this article generally refers to the 8-bit RISC line of Atmel AVR Microcontrollers.
- The acronym ARM was first used in 1983 and originally stood for "Acorn RISC Machine". Acorn Computers first RISC processor was used in the original Acorn Archimedes and was one of the first RISC processors used in small computers. However, when the company was incorporated in 1990, the acronym was changed to "Advanced RISC Machines", in light of the company's name "Advanced RISC Machines Ltd." At the time of the IPO in 1998, the company name was changed to "ARM Holdings, often just called ARM like the processors.

AVR Features

- Normally 8-bit
- 4–256 KB program memory
- 6–100-pin package
- Extended instruction set (multiply instructions and instructions for handling larger program memories)
- Extensive peripheral set
- AVR can achieve up to 1 MIPS per MHz up to 16MHz The AVR 8-bit microcontroller architecture was introduced in 1997

ARM Cortex M Features

- Normally 32-bit
- Normally 1 MB program memory
- 14–250-pin package
- ARM Cortex M can achieve up to 0.9 MIPS per MHz up to 400MHz
- Lots of features and companies !

Announced Year	
2004	Cortex-M3
2007	Cortex-M1
2009	Cortex-M0
2010	Cortex-M4(F)
2012	Cortex-M0+
2014	Cortex-M7(F)
2016	Cortex-M23
2016	Cortex-M33(F)

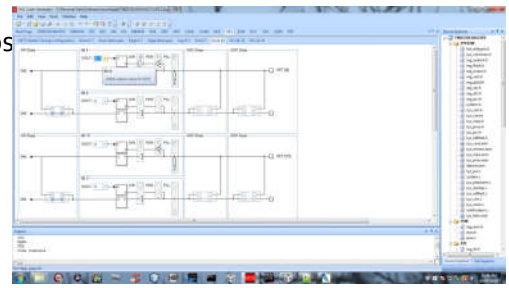
Producers

- Texas Instruments
- Atmel
- STMicroelectronics
- Renesas
- Philips
- NXP
- Nordic
- Toshiba
- Slicon Labs
- Altera
- Xilinx
- Actel
- Analog devices
- Apple
- Samsung

But we have to choose a producer

You can choose between Texas,

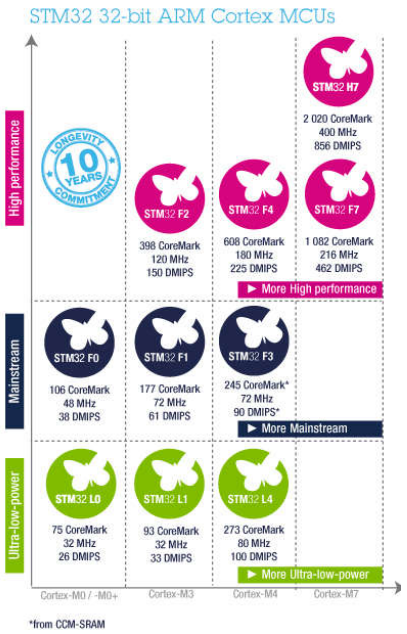
Mos



MCU selection Criteria

- Low power requirements
- Performance and maximum frequency
- Chip package
- Operation conditions (voltage, temperature, electromagnetic interference)
- Cost and availability
- Software development tool support and development kits
- Future upgradability
- Firmware packages and firmware security
- Availability of application notes, design examples, and support

MCU selection Criteria (Cont.)



Cortex Mo Features

ARM® Cortex®-M0 – 48 MHz	Product lines	Flash (Kbytes)	RAM (Kbytes)	Power supply	20-byte backup data	12-bit DAC	Comp.	Touch sense	Up to 2x SPI/ PS, 2x I²C	USART	CEC	CAN	USB
• Reset POR/PDR • 2x watchdogs • Hardware CRC • Internal RC • Crystal oscillators • PLL • RTC calendar • 16- and 32-bit timers • 1x12-bit ADC • Temperature sensor • Multiple-channel DMA • Single-wire debug • Unique ID	STM32F0x0 Value line	16 to 256	4 to 32	2.4 to 3.6 V					•	6			•
	STM32F0x1 Access line	16 to 256	4 to 32	2.0 to 3.6 V	•	•	•	•	•	8	•	•	
	STM32F0x2 USB line	16 to 128	4 to 16	2.0 to 3.6 V	•	•	•	•	•	4	•	•	• (crystal-less)
	STM32F0x8 Low-voltage line	32 to 256	4 to 32	1.8 V ± 8%	•	•	•	•	•	8	•		• (crystal-less)

Cortex M3 Features

Cortex®-M3 (DSP + FPU) - Up to 72 MHz	Product line	FCPU (MHz)	FLASH (bytes)	RAM (KB)	USB 2.0 FS	USB 2.0 FS OTG	FSMC	CAN 2.0B	3-phase MC timer	I²S	SDIO	Ethernet IEEE 1588	HDMI CEC
• -40 to +105 °C range • USART, SPI, I²C • 16- and 32-bit timers • Temperature sensor • Up to 3 x 12-bit ADC • Dual 12-bit DAC • Low voltage 2.0 to 3.6 V (5 V tolerant I/Os)	STM32F100 Value line	24	16 K to 512 K	4 to 32			•		•				•
	STM32F101	36	16 K to 1 M	4 to 80			•						
	STM32F102	48	16 K to 128 K	4 to 16	•								
	STM32F103	72	16 K to 1 M	6 to 96	•		•	•	•	•	•		
	STM32F105 STM32F107	72	64 K to 256 K	64		•	•	•	•	•		•	

Cortex M4 Features

Product lines	FCPU (MHz)	Flash (bytes)	RAM (KB)	Ethernet I/F IEEE 1588 / 2x CAN	Camera I/F	SDRAM I/F Dual Quad-SPI	SAI2 I/F SPDIF RX	Chrom-ART Graphic Accelerator™	TFT LCD controller	MPU OSI
Advanced lines										
STM32F469[1]	180	512 K to 2 M	384	• / •	•	• / •	• / •	•	•	•
STM32F429[1]	180	512 K to 2 M	256	• / •	•	• / •	• / •	•	•	
STM32F427[1]	180	1 to 2 M	256	• / •	•	• / •	• / •	•		
Foundation lines										
STM32F446	180	256 K to 512 K	128	/ •	•	• / •	• / •			
STM32F407[1]	168	512 K to 1 M	192	• / •	•					
STM32F405[1]	168	512 K to 1 M	192	•						

Product lines	FCPU (MHz)	Flash (Kbytes)	RAM (KB)	RUN current (µA/MHz)	STOP current (µA)	Small packages (mm)	FSMC (NOR/PSRAM/LCD support)	QSPI	DFSDM	CAN 2.0B	DAC	TRNG	DMA Static Acquisition Mode	USB 2.0 OTG FS
Access lines														
STM32F401	84	128 to 512	up to 96	Down to 128	Down to 10	Down to 3x3								•
STM32F410	100	64 to 128	32	Down to 89	Down to 6	Down to 2.553x 2.579					•	•	BAM	-
STM32F411	100	256 to 512	128	Down to 100	Down to 12	Down to 3.034x 3.22							BAM	•
STM32F412	100	512 to 1024	256	Down to 112	Down to 18	Down to 3.653x 3.651	•	•	•	•		•	BAM	• +LPM[1]
STM32F413[1]	100	1024 to 1536	320	Down to 115	Down to 18	Down to 3.951x 4.039	•	•	•	•	•	•	BAM+	• +LPM[1]

Cortex M7(F7) Features

Product		F_{CPU} (MHz)	L1 cache (I/D)	FPU	Flash (bytes)	RAM (KB) + 16K ITCM + 4K backup	JPEG codec	CAN	DFSDM	TFT LCD controller	MPPB-DSI
Advanced lines											
STM32F7x9[1] STM32F7x6[1]		216	16K+16K	Double Precision	1M to 2M (RWW)	512K (incl.128K DTCM)	•	3	•	•	•
STM32F7x7[1]		216	16K+16K	Double Precision	1M to 2M (RWW)		•	3	•	•	
STM32F7x6[1]		216	4K+4K	Single Precision	512K to 1M	320K (incl.64K DTCM)		2		•	
STM32F7x5	765	216	16K+16K	Double Precision	1M to 2M (RWW)	512K (incl.128K DTCM)		3	•		
	745	216	4K+4K	Single Precision	512K to 1M	320K (incl.64K DTCM)		2			
Foundation lines											
Product lines		F_{CPU} (MHz)	L1 cache (I/D)	FPU	Flash (bytes)	RAM (KB) + 16K ITCM + 4K backup	JPEG codec	CAN	DFSDM	PC-ROP (protected code execution)	USB HS PHY
STM32F7x3[1]		216	8K+8K	Single Precision	256K to 512K	256K (incl.64K DTCM)		1		•	•
STM32F7x2[1]		216	8K+8K	Single Precision	256K to 512K			1		•	

Cortex M7 (H7) Features

ARM® Cortex®-M7 – 400 MHz

CORE, MEMORIES AND ACCELERATION
- Cortex-M7 core @ 400 MHz
- 16KB+16KB I/D L1 Cache
- Double-precision FPU
- 4 x DMA

CONNECTIVITY
- 2 x USB2.0 OTG FS/HS
- 2 x SDMMC
- USART, UART, SPI, I²C
- 2 x CAN (1 x FD and 1 x TT/FD)
- HDMI-CEC
- FMC
- Analog (comp, AOP)

AUDIO
- 3 x I²S + audio PLL
- 4 x SAI
- 2 x 12-bit DAC
- SPDIF-RX

GRAPHIC
- LCD TFT controller
- JPEG Codec
- Chrom-ART Accelerator™

OTHER
- TRNG
- DFSDM
- 16- and 32-bit timers
- 3 x 14-bit ADC (2 Msps)
- Low voltage 1.7 to 3.6V
- Multi power domains
- -40 to +85 °C temperature range

STM32 H7 Product line	F$_{CPU}$ (MHz)	Core	Flash (bytes)	RAM (KB)	Dual Quad-SPI	Ethernet I/F IEEE 1588	Camera I/F	Security Services & Crypto
STM32H7x7*	Available in 2018							
STM32H7x5*	Available in 2018							
STM32H753	400	Cortex-M7	Up to 2MB (dual bank)	1MB (incl.128K DTCM) + 64K ITCM + 64KB bckup1 + 4K bckup2	•	•	•	•
STM32H743	400	Cortex-M7	Up to 2MB (dual bank)	1MB (incl.128K DTCM) + 64K ITCM + 64KB bckup1 + 4K bckup2	•	•	•	

Advantages of Cortex M

1.2.1 Low power

Compared to other 32-bit processor designs, Cortex®-M processors are relatively small. The Cortex-M processor designs are also optimized for low power consumption. Currently, many Cortex-M microcontrollers have power consumption of less than 200 µA/MHz, with some of them well under 100 µA/MHz. In addition, the Cortex-M processors also include support for sleep mode features and can be used with various advanced ultra-low power design technologies. All these allow the Cortex-M processors to be used in various ultra-low power microcontroller products.

Advantages of Cortex M (Cont.)

1.2.2 Performance

The Cortex®-M3 and Cortex-M4 processors can deliver over 3 CoreMark/MHz and 1.25 DMIPS/MHz (based on the Dhrystone 2.1 benchmark). This allows Cortex-M3 and Cortex-M4 microcontrollers to handle many complex and demanding applications. Alternatively you can run the application with a much slower clock speed to reduce power consumption.

1.2.3 Energy efficiency

Combining low power and high-performance characteristics, the Cortex®-M3 and Cortex-M4 processors have excellent energy efficiency. This means that, you can still do a lot of processing, with a limited supply of energy. Or you can get tasks done quicker and allow the system to stay in sleep mode for longer durations of time, enabling longer battery life in portable products.

Advantages of Cortex M (Cont.)

1.2.4 Code density

The Thumb® ISA provides excellent code density. This means that to achieve the same tasks, you need a smaller program size. As a result you can reduce cost and power consumption by using a microcontroller with smaller flash memory size, and chip manufacturers can produce microcontroller chips with smaller packages.

1.2.5 Interrupts

The Cortex®-M3 and Cortex-M4 processors have a configurable interrupt controller design, which can support up to 240 vectored interrupts and multiple levels of interrupt priorities (from 8 to 256 levels). Nesting of interrupts is automatically handled by hardware, and the interrupt latency is only 12 clock cycles for systems with zero wait state memory. The interrupt processing capability makes the Cortex-M processors suitable for many real-time control applications.[4]

Advantages of Cortex M (Cont.)

1.2.6 Ease of use, C friendly

The Cortex®-M processors are very easy to use. In fact, they are easier than compared to many 8-bit processors because Cortex-M processors have a simple, linear memory map, and there are no special architectural restrictions, which you often find in 8-bit microcontrollers (e.g., memory banking, limited stack levels, non-re-entrant code, etc.). You can program almost everything in C including the interrupt handlers.

1.2.7 Scalability

The Cortex®-M processor family allows easy scaling of designs from low-cost, simple microcontrollers costing less than a dollar to high-end microcontrollers running at 200 MHz or more. You can also find Cortex-M microcontrollers with multiprocessor designs. With all these, due to the consistency of the processor architecture, you only need one tool chain and you can reuse your software easily.

Advantages of Cortex M (Cont.)

1.2.8 Debug features

The Cortex®-M processors include many debug features that allow you to analyze design problems easily. Besides standard design features, which you can find in most microcontrollers like halting and single stepping, you can also generate a trace to capture program flow, data changes, profiling information, and so on. In multiple processor designs, the debug system of each Cortex-M processor can be linked together to share debug connections.

1.2.9 OS support

The Cortex®-M processors are designed with OS applications in mind. A number of features are available to make OS implementation easier and make OS operations more efficient. Currently there are over 30 embedded OSs available for Cortex-M processors.

Advantages of Cortex M (Cont.)

1.2.10 Versatile system features

The Cortex®-M3 and Cortex-M4 processors support a number of system features such as bit addressable memory range (bit band feature) and MPU (Memory Protection Unit).

1.2.11 Software portability and reusability

Since the architecture is very C friendly, you can program almost everything in standard ANSI C. One of ARM's initiatives called CMSIS (Cortex® Microcontroller Software Interface Standard) makes programming for Cortex-M processor based products even easier by providing standard header files and an API for standard Cortex-M processor functions. This allows better software reusability and also makes porting application code easier.

1.2.12 Choices (devices, tools, OS, etc.)

One of the best things about using Cortex®-M microcontrollers number amount of available choices. Besides the thousands of microcontroller devices available, you also have a wide range of coins on software development/debug tools, embedded OS, middleware, etc.

Applications of Cortex M

Microcontrollers: The Cortex-M processor family is ideally suited for microcontroller products.

This includes low-cost microcontrollers with small memory sizes and high-performance microcontrollers with high operation speeds. These microcontrollers can be used in consumer products, from toys to electrical appliances, or even specialized products for Information Technology (IT), industrial, or even medical systems.

Automotive: Another application for the Cortex-M3 and Cortex-M4 processors is in the automotive industry. As these processors offer great performance, very high energy efficiency, and low interrupt latency, they are ideal for many real-time control systems. In addition, the flexibility of the processor design (e.g., it supports up to 240 interrupt sources, optional MPU) makes it ideal for highly integrated ASSPs (Application Specific Standard Products) for the automotive industry. The MPU feature also provides robust memory protection, which is required in some of these applications.

Applications of Cortex M (Cont.)

Data communications: The processor's low power and high efficiency, coupled with instructions in Thumb®-2 for bit-field manipulation, make the Cortex-M3 and Cortex-M4 processors ideal for many communication applications, such as Bluetooth and ZigBee.

Industrial control: In industrial control applications, simplicity, fast response, and reliability are key factors. Again, the interrupt support features on Cortex-M3 and Cortex-M4 processors, including their deterministic behavior, automatic nested interrupt handling, MPU, and enhanced fault-handling, make them strong candidates in this area.

Consumer products: In many consumer products, a high-performance microprocessor (or several) is used. The Cortex-M3 and Cortex-M4 processors, being small, are highly efficient and low in power, and at the same time provide the performance required for handling complex GUIs on LCD panels and various communication protocols.

Systems-on-Chips (SoC): In some high-end application processor designs, Cortex-M processors are used in various subsystems such as audio processing engines, power management systems, FSM (Finite State Machine) replacement, I/O control task off loading, etc.

Applications of Cortex M (Cont.)

Mixed signal designs: In the IC design world, the digital and analog designs are converging. While microcontrollers contain more and more analogue components (e.g., ADC, DAC), some analog ICs such as sensors, PMIC (Power Management IC), and MEMS (Microelectromechanical Systems) now also include processors to provide additional intelligence. The low power capability and small gate count characteristics of the Cortex-M processors make it possible for them to be integrated on mixed signal IC designs.

Cost

There are already many Cortex-M3 and Cortex-M4 processor-based products on the market,[5] including low-end microcontrollers at less than 0.5 U.S. dollar, making the cost of ARM microcontrollers comparable to or lower than that of many 8-bit microcontrollers.

History

Over the years, ARM® has designed many processors, and many features of the Cortex®-M3 and Cortex-M4 processors are based on the successful technologies which have evolved from some of the processors designed in the past. To help you understand the variations of ARM processors and architecture versions, let's look at a little bit of ARM history.

ARM was formed in 1990 as Advanced RISC Machines Ltd., a joint venture between Apple Computers, Acorn Computer Group, and VLSI Technology. In 1991, ARM introduced the ARM6 processor family (used in Apple Newton, see Figure 1.4), and VLSI became the initial licensee. Subsequently, additional companies, including Texas Instruments, NEC, Sharp, and ST Microelectronics, licensed the ARM processor designs, extending the applications of ARM processors into mobile phones, computer hard disks, personal digital assistants (PDAs), home entertainment systems, and many other consumer products.

Nowadays, ARM partners ship in excess of 5 billion chips with ARM processors each year (7.9 billion in 2011[8]). Unlike many semiconductor companies,

History (Cont.)

ARM does not manufacture processors or sell the chips directly. Instead, ARM licenses the processor designs to business partners, including a majority of the world's leading semiconductor companies. Based on the ARM low-cost and power-efficient processor designs, these partners create their processors, micro-controllers, and system-on-chip solutions. This business model is commonly called IP licensing.

In addition to processor designs, ARM also licenses systems-level IP such as peripherals and memory controllers. To support the customers who use ARM products, ARM has developed a strong base of development tools, hardware, and software products to enable partners to develop their own products, and to enable software developers to develop software for ARM platforms.

History (Cont.)

FIGURE 1.4

The Apple Newton MessagePad H1000 PDA (based on ARM 610, released in 1993) placed next to an Apple iPhone 4, which is based on the Apple A4 processor that contains an ARM Cortex-A8 processor, released in 2010