STM32F4xx Seminar

Tomáš DRESLER
STM32 product series

4 product series

Common core peripherals and architecture:

- **STM32 F4 series - High performance with DSP (STM32F405/415/407/417)**
  - 168 MHz Cortex-M4 with DSP and CPU
  - Up to 192-Kbyte SRAM
  - Up to 1-Mbyte Flash
  - 2x USB 2.0 OTG FS/HS
  - 3-phase MC timer
  - 2x CAN 2.0B
  - SDIO 2x PS audio
  - Camera IF
  - Ethernet IEEE 1588
  - Crypto/hash processor and RNG

  - 120 MHz Cortex-M3 CPU
  - Up to 128-Kbyte SRAM
  - Up to 1-Mbyte Flash
  - 2x USB 2.0 OTG FS/HS
  - 3-phase MC timer
  - 2x CAN 2.0B
  - SDIO 2x PS audio
  - Camera IF
  - Ethernet IEEE 1588
  - Crypto/hash processor and RNG

- **STM32 F1 series - Connectivity line (STM32F105/107)**
  - 72 MHz Cortex-M3 CPU
  - Up to 64-Kbyte SRAM
  - Up to 256-Kbyte Flash
  - USB 2.0 OTG FS
  - 3-phase MC timer
  - 2x CAN 2.0B
  - 2x PS audio
  - Ethernet IEEE 1588

- **STM32 F1 series - Performance line (STM32F103)**
  - 72 MHz Cortex-M3 CPU
  - Up to 96-Kbyte SRAM
  - Up to 1-Mbyte Flash
  - USB FS device
  - 3-phase MC timer
  - CAN 2.0B
  - SDIO 2x PS

- **STM32 F1 series - USB Access line (STM32F102)**
  - 48 MHz Cortex-M3 CPU
  - Up to 16-Kbyte SRAM
  - Up to 128-Kbyte Flash
  - USB FS device

- **STM32 F1 series - Access line (STM32F101)**
  - 36 MHz Cortex-M3 CPU
  - Up to 80-Kbyte SRAM
  - Up to 1-Mbyte Flash

- **STM32 F1 series - Value line (STM32F100)**
  - 24 MHz Cortex-M3 CPU
  - Up to 32-Kbyte SRAM
  - Up to 512-Kbyte Flash
  - 3-phase MC timer
  - CEC

- **STM32 L1 series - Ultra-low-power (STM32L151/152)**
  - 32 MHz Cortex-M3 CPU
  - Up to 48-Kbyte SRAM
  - Up to 384-Kbyte Flash
  - USB FS device
  - Data EEPROM up to 12 Kbytes
  - LCD 8x40 4x44
  - Comparator
  - BOR
  - MSI VScale
  - AES 128-bit
STM32 – leading Cortex-M portfolio

Over 250 pin-to-pin compatible part numbers
STM32 F4 series

High-performance Cortex™-M4 MCU
STM32F4xx Block Diagram

- Cortex-M4 w/ FPU, MPU and ETM
- Memory
  - Up to 1MB Flash memory
  - 192KB RAM (including 64KB CCM data RAM)
  - FSMC up to 60MHz
- New application specific peripherals
  - USB OTG HS w/ ULPI interface
  - Camera interface
  - HW Encryption**: DES, 3DES, AES 256-bit, SHA-1 hash, RNG.
- Enhanced peripherals
  - USB OTG Full speed
  - ADC: 0.416µs conversion/2.4Msps, up to 7.2Msps in interleaved triple mode
  - ADC/DAC working down to 1.8V
  - Dedicated PLL for I²S precision
  - Ethernet w/ HW IEEE1588 v2.0
  - 32-bit RTC with calendar
  - 4KB backup SRAM in VBAT domain
  - 2 x 32bit and 8 x 16bit Timers
  - high speed USART up to 10.5Mb/s
  - high speed SPI up to 37.5Mb/s
- RDP (JTAG fuse)
- More I/Os in UFBGA 176 package

** Encryption is only available on STM32F415 and STM32F417
STM32F4 Series highlights 1/3

- Based on Cortex M4 core
  - The **new DSP and FPU instructions** combined to 168MHz
  - Over 30 new part numbers **pin-to-pin and software compatible** with existing STM32 F2 Series.

Advanced technology and process from ST:
- **Memory accelerator**: ART Accelerator™
- Multi AHB Bus Matrix
- 90nm process

Outstanding results:
- **210DMIPS** at 168MHz.
- Execution from Flash equivalent to **0-wait state** performance up to 168MHz thanks to ST ART Accelerator
STM32F4 Series highlights 2/3

More Memory
- Up to **1MB Flash** with option to permanent readout protection (**JTAG fuse**),
- **192kB SRAM**: 128kB on bus matrix + 64kB (Core Coupled Memory) on data bus dedicated to the CPU usage

Advanced peripherals
- **USB OTG High speed** 480Mbit/s
- **Ethernet MAC** 10/100 with IEEE1588
- **PWM High speed timers**: 168MHz max frequency
- **Crypto/Hash processor**, 32-bit random number generator (**RNG**)
- 32-bit RTC with calendar: with sub 1 second accuracy, and <1uA
Further improvements

- Low voltage: 1.8V to 3.6V VDD, down to 1.7*V on most packages
- Full duplex I²S peripherals
- 12-bit ADC: 0.41µs conversion/2.4Msp (7.2Msp in interleaved mode)
- High speed USART up to 10.5Mbits/s
- High speed SPI up to 37.5Mbits/s
- Camera interface up to 54MBytes/s

*external reset circuitry required to support 1.7V
STM32F4 portfolio

Flash size (bytes)

1 M
- STM32F417VG
- STM32F417ZG
- STM32F417IG
- STM32F415RG
- STM32F415VG
- STM32F415ZG

512 K
- STM32F407VG
- STM32F407ZG
- STM32F407IG
- STM32F405RG
- STM32F405VG
- STM32F405ZG

Legend:
- ▼ Ethernet, 2xUSB OTG, camera IF
- ▲ 1xUSB OTG FS/HS
- □ Encryption

Pin count
- 64 pins LQFP/CSP
- 100 pins LQFP
- 144 pins LQFP
- 176 pins LQFP/UFBSGA
Extensive tools and SW

- Evaluation board for full product feature evaluation
  - Hardware evaluation platform for all interfaces
  - Possible connection to all I/Os and all peripherals
- Discovery kit for cost-effective evaluation and prototyping
- Starter kits from 3rd parties available soon
- Large choice of development IDE solutions from the STM32 and ARM ecosystem

STM3240G-EVAL
$349

STM32F4DISCOVERY
$14.90
Tools for development – SW (examples)

- **Commercial ones:**
  - IAR – eval 32kB/30days for test  [RK-System]
  - Keil (ARM) – eval 32kB for test  [WG Electronics]

- **Based on GCC commercial:**
  - Atollic – Lite (no hex/bin, limited debug), [Kamami]
  - Raisonance – debug limited to 32kB
  - Rowley Crossworks – 30 days for test

- **Free**
  - STVP – FLASH prog.
  - STLink utility – FLASH prog. (+cmd line)
  - ST FlashLoader – FLASH prog.

- **Libraries (free)**
  - Standard peripherals library with CMSIS
  - USB device library
ARM Cortex M4 in few words
Cortex-M processors binary compatible
## Cortex-M feature set comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cortex-M0</th>
<th>Cortex-M3</th>
<th>Cortex-M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture Version</td>
<td>V6M</td>
<td>v7M</td>
<td>v7ME</td>
</tr>
<tr>
<td>Instruction set architecture</td>
<td>Thumb, Thumb-2</td>
<td>Thumb + Thumb-2</td>
<td>Thumb + Thumb-2, DSP, SIMD, FP</td>
</tr>
<tr>
<td>System Instructions</td>
<td>Thumb-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMIPS/MHz</td>
<td>0.9</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>Bus interfaces</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Integrated NVIC</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Number interrupts</td>
<td>1-32 + NMI</td>
<td>1-240 + NMI</td>
<td>1-240 + NMI</td>
</tr>
<tr>
<td>Interrupt priorities</td>
<td>4</td>
<td>8-256</td>
<td>8-256</td>
</tr>
<tr>
<td>Breakpoints, Watchpoints</td>
<td>4/2/0, 2/1/0</td>
<td>8/4/0, 2/1/0</td>
<td>8/4/0, 2/1/0</td>
</tr>
<tr>
<td>Memory Protection Unit (MPU)</td>
<td>No</td>
<td>Yes (Option)</td>
<td>Yes (Option)</td>
</tr>
<tr>
<td>Integrated trace option (ETM)</td>
<td>No</td>
<td>Yes (Option)</td>
<td>Yes (Option)</td>
</tr>
<tr>
<td>Fault Robust Interface</td>
<td>No</td>
<td>Yes (Option)</td>
<td>No</td>
</tr>
<tr>
<td>Single Cycle Multiply</td>
<td>Yes (Option)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hardware Divide</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>WIC Support</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bit banding support</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Single cycle DSP/SIMD</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Floating point hardware</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Bus protocol</td>
<td>AHB Lite</td>
<td>AHB Lite, APB</td>
<td>AHB Lite, APB</td>
</tr>
<tr>
<td>CMSIS Support</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Notes:*
- **Circled** indicates a feature that is either included or excluded based on the specific model.
Cortex M4
Cortex-M4 processor architecture

- **ARMv7ME Architecture**
  - Thumb-2 Technology
  - DSP and SIMD extensions
  - Single cycle MAC (Up to 32 x 32 + 64 -> 64)
  - Optional single precision FPU
  - Integrated configurable NVIC
  - Compatible with Cortex-M3

- **Microarchitecture**
  - 3-stage pipeline with branch speculation
  - 3x AHB-Lite Bus Interfaces

- **Configurable for ultra low power**
  - Deep Sleep Mode, Wakeup Interrupt Controller
  - Power down features for Floating Point Unit

- **Flexible configurations for wider applicability**
  - Configurable Interrupt Controller (1-240 Interrupts and Priorities)
  - Optional Memory Protection Unit
  - Optional Debug & Trace
Cortex-M4 overview

- Main Cortex-M4 processor features
  - ARMv7-ME architecture revision
    - Fully compatible with Cortex-M3 instruction set
  - Single-cycle multiply-accumulate (MAC) unit
  - Optimized single instruction multiple data (SIMD) instructions
  - Saturating arithmetic instructions
  - Optional single precision Floating-Point Unit (FPU)
  - Hardware Divide (2-12 Cycles), same as Cortex-M3
  - Barrel shifter (same as Cortex-M3)
  - Hardware divide (same as Cortex-M3)
The multiplier unit allows any MUL or MAC instructions to be executed in a single cycle:

- Signed/Unsigned Multiply
- Signed/Unsigned Multiply-Accumulate
- Signed/Unsigned Multiply-Accumulate Long (64-bit)

Benefits: Speed improvement vs. Cortex-M3

- 4x for 16-bit MAC (dual 16-bit MAC)
- 2x for 32-bit MAC
- up to 7x for 64-bit MAC
Cortex-M4 extended single cycle MAC

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>INSTRUCTIONS</th>
<th>CM3</th>
<th>CM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 x 16 = 32</td>
<td>SMULBB, SMULBT, SMULTB, SMULTT</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>16 x 16 + 32 = 32</td>
<td>SMLABB, SMLABT, SMLATB, SMLATT</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>16 x 16 + 64 = 64</td>
<td>SMLALBB, SMLALBT, SMLALTB, SMLALTT</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>16 x 32 = 32</td>
<td>SMULWB, SMULWT</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>(16 x 32) + 32 = 32</td>
<td>SMLAWB, SMLAWT</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>(16 x 16) ± (16 x 16) = 32</td>
<td>SMUAD, SMUADX, SMUSD, SMUSDX</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>(16 x 16) ± (16 x 16) + 32 = 32</td>
<td>SMLAD, SMLADX, SMLSD, SMLSDX</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>(16 x 16) ± (16 x 16) + 64 = 64</td>
<td>SMLALD, SMLALDX, SMLSLD, SMLSLDX</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>32 x 32 = 32</td>
<td>MUL</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>32 ± (32 x 32) = 32</td>
<td>MLA, MLS</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>32 x 32 = 64</td>
<td>SMULL, UMULL</td>
<td>5-7</td>
<td>1</td>
</tr>
<tr>
<td>(32 x 32) + 64 = 64</td>
<td>SMLAL, UMLAL</td>
<td>5-7</td>
<td>1</td>
</tr>
<tr>
<td>(32 x 32) + 32 + 32 = 64</td>
<td>UMAAL</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>32 ± (32 x 32) = 32 (upper)</td>
<td>SMMLA, SMMLAR, SMMLS, SMMLSR</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>(32 x 32) = 32 (upper)</td>
<td>SMMUL, SMMULR</td>
<td>n/a</td>
<td>1</td>
</tr>
</tbody>
</table>

All the above operations are single cycle on the Cortex-M4 processor.
Saturated arithmetic

- Intrinsically prevents overflow of variable by clipping to min/max boundaries and remove CPU burden due to software range checks

Benefits

- Audio applications

- Control applications
  - The PID controllers’ integral term is continuously accumulated over time. The saturation automatically limits its value and saves several CPU cycles per regulators
Single-cycle SIMD instructions

- Stands for **Single Instruction Multiple Data**
- It operates with **packed data**
- Allows to do simultaneously several operations with 8-bit or 16-bit data format
  - i.e.: dual 16-bit MAC (Result = 16x16 + 16x16 + 32)

**Benefits**
- Parallelizes operations (2x to 4x speed gain)
- Minimizes the number of Load/Store instruction for exchanges between memory and register file (2 or 4 data transferred at once), if 32-bit is not necessary
- Maximizes register file use (1 register holds 2 or 4 values)
Packed data types

- Byte or halfword quantities packed into words
- Allows more efficient access to packed structure types
- SIMD instructions can act on packed data
- Instructions to extract and pack data
Further optimization strategies

- Circular addressing alternatives
- Loop unrolling
- Caching of intermediate variables
- Extensive use of SIMD and intrinsics
Cortex-M4 - Final FIR Code

```c
sample = blockSize/4;
do {
    sum0 = sum1 = sum2 = sum3 = 0;
    statePtr = stateBasePtr;
    coeffPtr = (q31_t *) (S->coeffs);
    x0 = *(q31_t *) (statePtr++);
    x1 = *(q31_t *) (statePtr++);
    i = numTaps>>2;
    do {
        c0 = *(coeffPtr++);
        x2 = *(q31_t *) (statePtr++);
        x3 = *(q31_t *) (statePtr++);
        sum0 = __SMLALD(x0, c0, sum0);
        sum1 = __SMLALD(x1, c0, sum1);
        sum2 = __SMLALD (x2, c0, sum2);
        sum3 = __SMLALD (x3, c0, sum3);
        c0 = *(coeffPtr++);
        x0 = *(q31_t *) (statePtr++);
        x1 = *(q31_t *) (statePtr++);
        sum0 = __SMLALD(x0, c0, sum0);
        sum1 = __SMLALD(x1, c0, sum1);
        sum2 = __SMLALD (x2, c0, sum2);
        sum3 = __SMLALD (x3, c0, sum3);
    } while (--i);
    *pDst++ = (q15_t) (sum0>>15);
    *pDst++ = (q15_t) (sum1>>15);
    *pDst++ = (q15_t) (sum2>>15);
    *pDst++ = (q15_t) (sum3>>15);
}
while(--sample);
```

Uses loop unrolling, SIMD intrinsics, caching of states and coefficients, and work around circular addressing by using a large state buffer.

Inner loop is 26 cycles for a total of 16, 16-bit MACs.

Only 1.625 cycles per filter tap!
Cortex-M4 - FIR performance

- DSP assembly code = 1 cycle
- Cortex-M4 standard C code takes 12 cycles
- Using circular addressing alternative = 8 cycles
- After loop unrolling < 6 cycles
- After using SIMD instructions < 2.5 cycles
- After caching intermediate values ~ 1.6 cycles

Cortex-M4 C code now comparable in performance
Cortex M4

Floating Point Unit
Overview

- **FPU: Floating Point Unit**
  - Handles “real” number computation
  - Standardized by IEEE.754-2008
    - Number format
    - Arithmetic operations
    - Number conversion
    - Special values
    - 4 rounding modes
    - 5 exceptions and their handling

- **ARM Cortex-M FPU ISA**
  - Supports
    - Add, subtract, multiply, divide
    - Multiply and accumulate
    - Square root operations
C language example

```c
float function1(float number1, float number2)
{
    float temp1, temp2;
    temp1 = number1 + number2;
    temp2 = number1/temp1;
    return temp2;
}
```

Call Soft-FPU

1 assembly instruction
Performances

- Time execution comparison for a 29 coefficient FIR on float 32 with and without FPU (CMSIS library)
Rounding issues

- The precision has some limits
  - Rounding errors can be accumulated along the various operations and may provide inaccurate results (do not do financial operations with floatings…)

- Few examples
  - If you are working on two numbers in different base, the hardware automatically « denormalizes » one of the two numbers to make the calculation in the same base
  - If you are subtracting two very close numbers, you are losing the relative precision (also called cancellation error)

- If you are « reorganizing » the various operations, you may not obtain the same result because of the rounding errors…
ARM Cortex-M FPU
Introduction

- Single precision FPU

- Conversion between
  - Integer numbers
  - Single precision floating point numbers
  - Half precision floating point numbers

- Handling floating point exceptions (Untrapped)

- Dedicated registers
  - 32 single precision registers (S0-S31) which can be viewed as 16 Doubleword registers for load/store operations (D0-D15)
  - FPSCR for status & configuration
Modifications vs IEEE 754

- **Full Compliance mode**
  - Process all operations according to IEEE 754

- **Alternative Half-Precision format**
  - \((-1)^s \times (1 + \sum(N_i.2^{-i})) \times 2^{16}\) and no de-normalize number support

- **Flush-to-zero mode**
  - De-normalized numbers are treated as zero
  - Associated flags for input and output flush

- **Default NaN mode**
  - Any operation with an NaN as an input or that generates a NaN returns the default NaN
Complete implementation

- Cortex-M4F does **NOT** support all operations of IEEE 754-2008

- Full implementation is done by software

- Unsupported operations
  - Remainder (% operator)
  - Round FP number to integer-value FP number
  - Binary to decimal conversions
  - Decimal to binary conversions
  - Direct comparison of Single Precision (SP) and Double Precision (DP) values
Floating-Point Status & Control Register

- **Condition code bits**
  - negative, zero, carry and overflow (update on compare operations)

- **ARM special operating mode configuration**
  - half-precision, default NaN and flush-to-zero mode

- **The rounding mode configuration**
  - nearest, zero, plus infinity or minus infinity

- **The exception flags**
  - Inexact result flag may not be routed to the interrupt controller…
FPU instructions
<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Assembler</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute value</td>
<td>of float</td>
<td>VABS.F32</td>
<td>1</td>
</tr>
<tr>
<td>Negate</td>
<td>float and multiply float</td>
<td>VNEG.F32</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VNMUL.F32</td>
<td>1</td>
</tr>
<tr>
<td>Addition</td>
<td>floating point</td>
<td>VADD.F32</td>
<td>1</td>
</tr>
<tr>
<td>Subtract</td>
<td>float</td>
<td>VSUB.F32</td>
<td>1</td>
</tr>
<tr>
<td>Multiply</td>
<td>float</td>
<td>VMUL.F32</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>then accumulate float</td>
<td>VMLA.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>then subtract float</td>
<td>VMLS.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>then accumulate then negate float</td>
<td>VNMLA.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>the subtract the negate float</td>
<td>VNMLS.F32</td>
<td>3</td>
</tr>
<tr>
<td>Multiply (fused)</td>
<td>then accumulate float</td>
<td>VFMA.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>then subtract float</td>
<td>VFMS.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>then accumulate then negate float</td>
<td>VFNMA.F32</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>then subtract then negate float</td>
<td>VFNMS.F32</td>
<td>3</td>
</tr>
<tr>
<td>Divide</td>
<td>float</td>
<td>VDIV.F32</td>
<td>14</td>
</tr>
<tr>
<td>Square-root</td>
<td>of float</td>
<td>VSQRT.F32</td>
<td>14</td>
</tr>
</tbody>
</table>
## FPU compare & convert instructions

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Assembler</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compare</td>
<td>float with register or zero</td>
<td>VCMP.F32</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>float with register or zero</td>
<td>VCMPE.F32</td>
<td>1</td>
</tr>
<tr>
<td>Convert</td>
<td>between integer, fixed-point</td>
<td>VCVT.F32</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>half precision and float</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## FPU Load/Store Instructions

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Assembler</th>
<th>Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>multiple doubles (N doubles)</td>
<td>VLDM.64</td>
<td>1+2*N</td>
</tr>
<tr>
<td></td>
<td>multiple floats (N floats)</td>
<td>VLDM.32</td>
<td>1+N</td>
</tr>
<tr>
<td></td>
<td>single double</td>
<td>VLDR.64</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>single float</td>
<td>VLDR.32</td>
<td>2</td>
</tr>
<tr>
<td>Store</td>
<td>multiple double registers (N doubles)</td>
<td>VSTM.64</td>
<td>1+2*N</td>
</tr>
<tr>
<td></td>
<td>multiple float registers (N doubles)</td>
<td>VSTM.32</td>
<td>1+N</td>
</tr>
<tr>
<td></td>
<td>single double register</td>
<td>VSTR.64</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>single float register</td>
<td>VSTR.32</td>
<td>2</td>
</tr>
<tr>
<td>Move</td>
<td>top/bottom half of double to/from core</td>
<td>VMOV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>register</td>
<td>VMOV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>immediate/float to float-register</td>
<td>VMOV</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>two floats/one double to/from core registers</td>
<td>VMOV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>one float to/from core register</td>
<td>VMRS</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>floating-point control/status to core</td>
<td>VMSR</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>register to floating-point control/status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pop</td>
<td>double registers from stack</td>
<td>VPOP.64</td>
<td>1+2*N</td>
</tr>
<tr>
<td></td>
<td>float registers from stack</td>
<td>VPOP.32</td>
<td>1+N</td>
</tr>
<tr>
<td>Push</td>
<td>double registers to stack</td>
<td>VPUSH.64</td>
<td>1+2*N</td>
</tr>
<tr>
<td></td>
<td>float registers to stack</td>
<td>VPUSH.32</td>
<td>1+N</td>
</tr>
</tbody>
</table>
STM32F4xx
System Peripherals
Real-time performance

32-bit multi-AHB bus matrix

Cortex-M4 with CPU
168 MHz

DMA transfers of the graphical icons from Flash to display

DMA transfers of the compressed audio stream to 16kByte SRAM block

MP3 decoder code execution by core

Access to the MP3 data for decompression

Decompressed audio stream to 112kByte SRAM block

DMA transfer to audio output stage (I2S)

User interface:
DMA transfers of the graphical icons from Flash to display
System Architecture – Role of the ART accelerator

Branch Cache stores 8 rows of 128-bit data (literals)

Flash

- I1- 32-bit
- I2- 32-bit
- I3- 32-bit
- I4- 32-bit

Branch Cache stores the 64 LRU branches and feeds the CPU without latency in case of a Hit.
System Architecture – Flash performance

Without prefetch

Read ins 1, 2, 3, 4
Gives ins 1, 2, 3, 4
Read ins 5, 6, 7, 8
Gives ins 5, 6, 7, 8
System Architecture – Flash performance

Cortex-M3 pipeline

@ : address requested
F: Fetch stage
D: Decode stage
E: Execute stage

@ 1 Wait data F 1 D 1 E 1

@ 2 F 2 D 2 E 2

@ 3 F 3 D 3 E 3

@ 4 F 4 D 4 E 4

@ 5 F 5 D 5 E 5

@ 6 F 6 D 6 E 6

@ 7 F 7 D 7 E 7

@ 8 F 8 D 8 E 8

With prefetch

ins 1 fetch ins 2 fetch ins 3 fetch ins 4 fetch ins 5 fetch ins 6 fetch ins 7 fetch ins 8 fetch

Read ins 1, 2, 3, 4 Gives ins 1, 2, 3, 4 Gives ins 5, 6, 7, 8

Read Ins 5, 6, 7, 8 Read Ins 9, 10, ...
The **Bootloader** supports

- USART1(PA9/PA10)
- USART3(PC10/PC11 or PB10/PB11)
- CAN2(PB5/PB13)
- USB OTG FS in Device mode (PA11/PA12) through DFU (device firmware upgrade)

**Note**

- The DFU/CAN may work w/ different value of external quartz in the range of 4-26 MHz, and the USART uses the internal HSI
- This Bootloader uses the same USART, CAN and DFU protocols as for STM32F2xx/STM32F10x
Flash Features Overview

- **Flash Features:**
  - Up to 1MB (sectors 16kB, 64kB and 128kB)
  - Endurance: 10K cycles by sector / 20 years retention
  - 32-bit Word Program time: 12µs (Typ)

- **Flash interface (FLITF) Features:**
  - 128b wide interface with prefetch buffer and data cache, instruction cache
  - Option Bytes loader
  - Flash program/Erase operations
  - Types of Protection:
    - Readout Protection: Level 1 and Level 2 (JTAG Fuse)
    - Write Protection (sector by sector)

- **The Information Block consists of:**
  - 30 kB for System Memory: contains embedded bootloader.
  - 16 B for Small Information block (SIF): contains 8 option bytes + its complementary part (write/read protection, BOR configuration, IWDG configuration, user data)
  - 512 Bytes OTP: one-time programmable
## Flash Operations

### Relation between CPU clock frequency and Flash memory read time

<table>
<thead>
<tr>
<th>Wait states (WS) (LATENCY)</th>
<th>HCLK clock frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage range 2.7 V - 3.6 V</td>
</tr>
<tr>
<td>0WS (1 CPU cycle)</td>
<td>0 &lt; HCLK &lt;= 30</td>
</tr>
<tr>
<td>1WS (2 CPU cycle)</td>
<td>30 &lt; HCLK &lt;= 60</td>
</tr>
<tr>
<td>2WS (3 CPU cycle)</td>
<td>60 &lt; HCLK &lt;= 90</td>
</tr>
<tr>
<td>3WS (4 CPU cycle)</td>
<td>90 &lt; HCLK &lt;= 120</td>
</tr>
<tr>
<td>4WS (5 CPU cycle)</td>
<td>120 &lt; HCLK &lt;= 150</td>
</tr>
<tr>
<td>5WS (6 CPU cycle)</td>
<td>150 &lt; HCLK &lt;= 168</td>
</tr>
<tr>
<td>6WS (7 CPU cycle)</td>
<td>144 &lt; HCLK &lt;= 168</td>
</tr>
<tr>
<td>7WS (8 CPU cycle)</td>
<td>126 &lt; HCLK &lt;= 144</td>
</tr>
</tbody>
</table>

**Note:** Latency when VOS bit in PWR_CR is equal to ‘1’
Flash Protections

Level 1
RDP ≠ 0xCC
RDP ≠ 0xAA

- Readout protection
- BLOCKED access to memory from SRAM, system memory and JTAG
- Remove readout protection possible after full erase of the memory and its blank verification

Level 2
RDP=0xCC

- JTAG fuse
- No un-protection possible
- JTAG disabled
- System memory disabled
- User settings protected

Level 0
RDP=0xAA

- No readout protection
- Full access to memory from SRAM, system memory and JTAG
CRC Features

- CRC-based techniques are used to verify data transmission or storage integrity
- Uses CRC-32 (Ethernet) polynomial: \(0x4C11DB7\)
  \[X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^{8} + X^{7} + X^{5} + X^{4} + X^{2} + X + 1\]
- Single input/output 32-bit data register
- CRC computation done in 4 AHB clock cycles (HCLK)
- General-purpose 8-bit register (can be used for temporary storage)
DMA Features

- Dual AHB master bus architecture, one dedicated to memory accesses and one dedicated to peripheral accesses.

- 8 streams for each DMA controller, up to 8 channels (requests) per stream (2 DMA controllers in STM32F4xx family). Channel selection for each stream is software-configurable.

- 4x32-Bits FIFO memory for each Stream (FIFO mode can be enabled or disabled).

- Independent source and destination transfer width (byte, half-word, word): when the source and destination data widths are different, the DMA automatically packs/unpacks data to optimize the bandwidth. (this feature is available only when FIFO mode is enabled)

- Double buffer mode (double buffer mode can enabled or disabled).

- Support software trigger for memory-to-memory transfers (available for the DMA2 controller streams only)
DMA Features

- The number of data to be transferred can be managed either by the DMA controller or by the peripheral.

- Independent Incrementing or Non-Incrementing addressing for source and destination. Possibility to set increment offset for peripheral address.

- Supports incremental burst transfers of 4, 8 or 16 beats. The size of the burst is software-configurable, usually equal to half the FIFO size of the peripheral.

- Each stream supports circular buffer management.

- 5 event flags logically ORed together in a single interrupt request for each stream.

- Priorities between DMA stream requests are software-programmable.
Streams and Channels configuration

- Each DMA Stream is connected to 8 channels (requests).

- Software selection of which channel should be active for a given stream by setting CHSEL[2:0] bits in DMA_SxCR register.

- Only one Channel can be active for a given Stream.

- A Channel may be not connected to any physical request on the product (ie. DMA1 Stream1 Channel 0).

- A Channel may also be connected to more than one request from the same peripheral (ie. DMA1 Stream1 Channel 4 is connected to TIM2_UP and TIM2_CH3 requests).

- Software requests are used for Memory-to-Memory transfers and are available only on DMA2 controller.
FIFO: Data Packing/Unpacking

- When FIFO mode is enabled (direct mode disabled) the DMA manage the data format difference between source and destination (data Packing and Unpacking).
- Supported operations:
  - 8-bit / 16-bit → 32-bit / 16-bit (Packing)
  - 32-bit / 16-bit → 8-bit / 16-bit (Unpacking)
- This feature allows to reduce software overhead and CPU load.

**Data Packing Example (8-bit → 32-bit)**
- Source data width = 8-bit
- Destination data width = 32-bit
- 8 transfers are performed from source to DMA FIFO.
- 2 transfers are performed from DMA FIFO to destination.

**Data Unpacking Example (32-bit → 16-bit)**
- Source data width = 32-bit
- Destination data width = 16-bit
- 2 transfers are performed from source to DMA FIFO.
- 4 transfers are performed from DMA FIFO to destination.
FIFO: Threshold & Burst mode

- **Threshold:**
  - Threshold level determines when the data in the FIFO should be transferred to/from Memory.
  - There are 4 threshold levels:
    - ¼ FIFO Full, ½ FIFO Full, ¾ FIFO Full, FIFO Full
  - When the FIFO threshold is reached, the FIFO is filled/flushed from/to the Memory location.

- **Burst/Single mode:**
  - Burst mode is available only when FIFO mode is enabled (direct mode disabled)
  - Burst mode allows to configure the amount of data to be transferred without CPU/DMA interruption.
  - Available Burst modes:
    - INC4: 1 burst = 4-beats (4 Words, 8 Half-Words or 16 Bytes)
    - INC8: 1 burst = 8-beats (8 Half-Words or 16 Bytes)
    - INC16: 1 burst = 16-beats (16 Bytes)
  - When setting Burst mode, the FIFO threshold should be compatible with Burst size:

<table>
<thead>
<tr>
<th>Memory Data Size</th>
<th>Burst Size</th>
<th>Allowed Threshold levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byte</td>
<td>4-Beats (INC4)</td>
<td>¼, ½, ¾ and Full</td>
</tr>
<tr>
<td></td>
<td>8-Beats (INC8)</td>
<td>½ &amp; Full</td>
</tr>
<tr>
<td></td>
<td>16-Beats (INC16)</td>
<td>Full</td>
</tr>
<tr>
<td>Half-Word</td>
<td>4-Beats (INC4)</td>
<td>½ &amp; Full</td>
</tr>
<tr>
<td></td>
<td>8-Beats (INC8)</td>
<td>Full</td>
</tr>
<tr>
<td>Word</td>
<td>4-Beats (INC4)</td>
<td>Full</td>
</tr>
</tbody>
</table>

**Notes:**
- For Half-Word Memory size, INC16 is not possible.
- For Word Memory size, INC8 and INC16 are not possible.
Circular & Double Buffer modes

- **Circular mode:**
  - All FIFO features and DMA events (TC, HT, TE) are available in this mode.
  - The number of data items is automatically reloaded and transfer restarted.
  - This mode is NOT available for Memory-to-Memory transfers.

- **Double Buffer mode:** (circular mode only)
  - Two Memory address registers are available (DMA_SxM0AR & DMA_SxM1AR).
  - Allows switch between two Memory buffers to be managed by hardware.
  - Memory-to-Memory mode is not allowed.
  - A flag & control bit (CT) is available to monitor which destination is being used for data transfer.
  - TC flag is set when transfer to memory location 0 or 1 is complete.
RESET Sources

- **System RESET**
  - Resets all registers except some RCC registers and Backup domain
  - **Sources**
    - Low level on the NRST pin (External Reset)
    - WWDG end of count condition
    - IWDG end of count condition
    - A software reset (through NVIC)
    - Low power management Reset

- **Power RESET**
  - Resets all registers except the Backup domain
  - **Sources**
    - Power On/Power down Reset (POR/PDR)
    - BOR
    - Exit from STANDBY

- **Backup domain RESET**
  - Resets in the Backup domain: RTC registers + Backup Registers + RCC BDCR register
  - **Sources**
    - BDRST bit in RCC BDCR register
    - POWER Reset
Power Supply

- $V_{DD} = 1.8$ V to 3.6 V. External Power Supply for I/Os and the internal regulator. The supply voltage can drop to 1.7 when the PDR_ON is connected to VSS and the device operates in the 0 to 70° C.

- $V_{DDA} = 1.8$ V to 3.6 V: External Analog Power supplies for ADC, DAC, Reset blocks, RCs and PLLs.

- $V_{CAP} =$ Voltage regulator external capacitors (also 1.2V supply in Regulator bypass mode)

- $V_{BAT} = 1.65$ to 3.6 V: power supply for Backup domain when $V_{DD}$ is not present.

Power pins connection:

- $V_{DD}$ and $V_{DDA}$ must be connected to the same power source
- $V_{SS}, V_{SSA}$ must be tight to ground
- $2.4\text{V} \leq V_{REF+} \leq V_{DDA}$ when $V_{DDA} \geq 2.4$
- $V_{REF+} = V_{DDA}$ when $V_{DDA} < 2.4$
Power supply monitoring POR, PDR, PVD

- Integrated POR / PDR circuitry:
  - For devices operating from 1.8 to 3.6 V, there is no BOR and the reset is released when \( V_{DD} \) goes above POR level and asserted when \( V_{DD} \) goes below PDR level
  - POR and PDR have 40mV hysteresis

- Programmable Voltage Detector
  - Enabled by software
  - Monitor the \( V_{DD} \) power supply by comparing it to a threshold
  - Threshold configurable from 1.9V to 3.1V by step of 100mV
  - Generate interrupt through EXTI Line16 (if enabled) when \( V_{DD} < \text{Threshold} \) and/or \( V_{DD} > \text{Threshold} \).

Can be used to generate a warning message and/or put the MCU into a safe state
Brown Out Reset (BOR)

- During power on, the Brown out reset (BOR) keeps the device under reset until the supply voltage reaches the specified $V_{\text{BOR}}$ threshold.
  - No need for external reset circuit
- BOR have a typical hysteresis of 100mV
- BOR Levels are configurable by option bytes:
  - BOR OFF: 2.1 V at power on and 1.62 V at power down
  - BOR LOW (DEFAULT): 2.4 V at power on and 2.1 V at power down
  - BOR MEDIUM: 2.7 V at power on and 2.4 V at power down
  - BOR HIGH: 3.6 V at power on and 2.7 V at power down
Supply monitoring and Reset circuitry

At startup:

- POR/PDR - Always ON (or CSP64 bounding option)
- Brown Out Reset (BOR) - Always ON (can be switched off after option byte loading)
- Programmable Voltage Detection (PVD) – ON/OFF.
  - PVD enable/disable bit is controlled by software via a dedicated bit (PVDE).
Backup Domain

- Backup Domain
  - RTC unit and 4KB Backup RAM
  - LVR for the backup RAM (with switch off option)
- VBAT independent voltage supply
  - Automatic switch-over to V\textsubscript{BAT} when V\textsubscript{DD} goes below PDR level
    - No current sunk on V\textsubscript{BAT} when V\textsubscript{DD} present
    - Prevent from power line down
- 1 Wakeup pin and 2 RTC Alternate functions pins (RTC\_AF1 and RTC\_AF2)
- Backup SRAM
  - 4 kB of backup SRAM accessible only from the CPU
  - Can store sensitive data (crypto keys)
  - Backup SRAM is powered by a dedicated low power regulator in V\textsubscript{BAT} mode. Its content is retained even in Standby and V\textsubscript{BAT} mode when the low power backup regulator is enabled.
  - The backup SRAM is not mass erased by an tamper event.
STM32F4xx Low power modes features

- The STM32F4xx features 3 low power modes
  - **SLEEP** (core stopped, peripherals running) ~2mA @2MHz (38mA @120MHz)
  - **STOP** (clocks stopped, RAM, registers kept) ~1mA current consumption
  - **STANDBY** (only backup domain kept, return via RESET)
- **VBAT** mode (like in **STANDBY** mode).

- The STM32F4xx features options to decrease the consumption during low power modes
  - Peripherals clock stopped automatically during sleep mode (S/W)
  - Flash Power Down mode
  - LVR and Backup RAM disable option

- The STM32F4xx features many sources to wakeup the system from low power modes:
  - Wakeup pin (PA0) / NRST pin
  - RTC Alarm (Alarm A and Alarm B)
  - RTC Wakeup Timer interrupt
  - RTC Tamper events
  - RTC Time Stamp Event
  - IWDG Reset event
## Wakeup time from Low Power Modes

<table>
<thead>
<tr>
<th>Low power mode</th>
<th>Conditions</th>
<th>Wakeup time in µs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sleep</strong> mode</td>
<td>regulator in Run mode</td>
<td>1 Typ</td>
</tr>
<tr>
<td><strong>Stop</strong> mode</td>
<td>regulator in low power mode</td>
<td>13 Typ</td>
</tr>
<tr>
<td><strong>Stop</strong> mode</td>
<td>regulator in low power mode and Flash in Deep power down mode</td>
<td>17 Typ</td>
</tr>
<tr>
<td><strong>Standby</strong> mode</td>
<td></td>
<td>110 Typ</td>
</tr>
<tr>
<td><strong>Standby</strong> mode</td>
<td></td>
<td>375 Typ</td>
</tr>
</tbody>
</table>
STM32F4 - clock features

Four oscillators on board
- **HSE** (High Speed External Osc) 4..26MHz (can be bypassed by and ext. Oscillator)
- **HSI** (High Speed Internal RC): factory trimmed internal RC oscillator 16MHz +/- 1
- **LSI** (Low Speed Internal RC): 32kHz internal RC used for **IWDG**, optionally RTC and AWU
- **LSE** (Low Speed External oscillator): 32.768kHz osc (can be bypassed by an external Osc)
  - precise time base with very low power consumption (max 1µA).
  - optionally drives the RTC for Auto Wake-Up (AWU) from STOP/STANDBY mode.

Two PLLs
- **Main PLL** (**PLL**) clocked by HSI or HSE used to generate the System clock (up to 168MHz), and 48 MHz clock for USB OTG FS, SDIO and RNG. PLL input clock in the range 1-2 MHz.
- **PLLI2S PLL** (**PLLI2S**) used to generate a clock to achieve HQ audio performance on the I²S interface.

More security
- **Clock Security System** (**CSS**, enabled by software) to backup clock in case of HSE clock failure (HSI feeds the system clock) – linked to Cortex NMI interrupt
- **Spread Spectrum Clock Generation** (**SSCG**, enabled by software) to reduce the spectral density of the electromagnetic interference (EMI) generated by the device
**Watchdogs**

- **Independent Watchdog (IWDG)**
  - Dedicated low speed clock (LSI)
  - HW and SW way of enabling
  - IWDG clock still active if main clock fails
  - Still functional in Stop/Standby
  - Wake-up from stop/standby
  - Min-max Timeout values \(125\text{us} \ldots 32.7\text{s}\)

- **Window Watchdog (WWDG)**
  - Configurable Time Window
  - Can detect abnormally early or late application behavior
  - Conditional Reset
  - WWDG Reset flag
  - Timeout value @42MHz (PCLK1): \(97.52\text{us} \ldots 49.93\text{ms}\)
STM32F4
Standard Peripherals
**GPIO features**

- Up to 140 multifunction bi-directional I/O ports available on 176 pin package
- Almost standard I/Os are 5V tolerant
- All Standard I/Os are shared in 9 ports (GPIOA..GPIOI)
- Atomic Bit Set and Bit Reset using BSRR register
- GPIO connected to AHB bus: max toggling frequency \( = \frac{f_{\text{AHB}}}{2} = 84 \, \text{MHz} \)
- Configurable Output Speed up to 100 MHz (2MHz,25MHz,50MHz,100MHz)
- Locking mechanism (GPIOx_LCKR) provided to freeze the I/O configuration
- Up to 140 GPIOs can be set-up as external interrupt (up to 16 lines at time) able to wake-up the MCU from low power modes
- Most of the I/O pins are shared with Alternate Functions pins connected to onboard peripherals through a multiplexer that allows only one peripheral’s alternate function to be connected to an I/O pin at a time
**GPIO Configuration Modes**

<table>
<thead>
<tr>
<th>MODER(i) [1:0]</th>
<th>OTYPER(i) [1:0]</th>
<th>PUPDR(i) [1:0]</th>
<th>I/O configuration</th>
</tr>
</thead>
</table>
| 01             | 0              | 0              | **Output Push Pull**  
                |                 | 0              | **Output Push Pull with Pull-up**  
                |                 | 1              | **Output Push Pull with Pull-down**  
|                | 1              | 0              | **Output Open Drain**  
                |                 | 0              | **Output Open Drain with Pull-up**  
                |                 | 1              | **Output Open Drain with Pull-down**  
| 10             | 0              | 0              | **Alternate Function Push Pull**  
                |                 | 0              | **Alternate Function PP Pull-up**  
                |                 | 1              | **Alternate Function PP Pull-down**  
|                | 1              | 0              | **Alternate Function Open Drain**  
                |                 | 0              | **Alternate Function OD Pull-up**  
                |                 | 1              | **Alternate Function OD Pull-down**  
| 00             | x              | 0              | **Input floating**  
                |                 | 0              | **Input with Pull-up**  
                |                 | 1              | **Input with Pull-down**  
| 11             | x              | x              | **Analog mode**  

* In output mode, the I/O speed is configurable through OSPEEDR register: 2MHz, 25MHz, 50MHz or 100 MHz

(1) VDD_FT is a potential specific to five-volt tolerant I/Os and different from VDD.
Alternate Functions features

- Most of the peripherals shares the same pin (like USARTx_Tx, TIMx_CH2, I2Cx_SCL, SPIx_MISO, EVENTOUT…)

- Alternate functions multiplexers prevent to have several peripheral’s function pin to be connected to a specific I/O at a time.

- Some Alternate function pins are remapped to give the possibility to optimize the number of peripherals used in parallel.
System Configuration

- Configure (2 bits) the type of memory accessible at address 0x00000000. These bits are used to select the physical remap by software and so, bypass the BOOT pins.
  - 00: Main Flash memory mapped at 0x0000 0000
  - 01: System Flash memory mapped at 0x0000 0000
  - 10: FSMC (NOR/SRAM bank1) mapped at 0x0000 0000
  - 11: Embedded SRAM (112kB) mapped at 0x0000 0000

- Select the Ethernet PHY interface (MII or RMII)

- Manage the external interrupt line connection to the GPIOs:
  * x can be 0 to 15 for all ports]
EXTI module: from pin to NVIC

GPIOA_0
GPIOB_0
GPIOI_0
GPIOA_1
GPIOB_1
GPIOI_1
GPIOA_15
GPIOB_15
GPIOI_15

Channel 0
Channel 1
Channel 15

Input floating

Enable
DISABLE

PVD
RTC_Alarm
USB OTG FS Wkup
ETH Wkup
USB OTG HS Wkup
RTC Tamper
RTC Wkup

Event

Interrupt

Wakeup

Exti_0
Exti_1
Exti_2
Exti_3
Exti_4
Exti_9-5
Exti_15-10
PVD_IRQ
RTC_IRQ

CORTEX M4

NVIC

STM32 F4
ADC Features (1/2)

- 3 ADCs: ADC1 (master), ADC2 and ADC3 (slaves)
- Maximum frequency of the ADC analog clock is 36MHz.
- 12-bits, 10-bits, 8-bits or 6-bits configurable resolution.
- ADC conversion rate with 12 bit resolution is up to:
  - 2.4 M.sample/s in single ADC mode,
  - 4.5 M.sample/s in dual interleaved ADC mode,
  - 7.2 M.sample/s in triple interleaved ADC mode.
- Conversion range: 0 to 3.6 V.
- ADC supply requirement: VDDA = 2.4V to 3.6V at full speed and down to 1.65V at lower speed.
- Up to 24 external channels.
- 3 ADC1 internal channels connected to:
  - Temperature sensor,
  - Internal voltage reference: VREFINT (1.2V typ),
  - VBAT for internal battery monitoring.
ADC Features (2/2)

- External trigger option for both regular and injected conversion.
- Single and continuous conversion modes.
- Scan mode for automatic conversion of channel 0 to channel ‘n’.
- Left or right data alignment with in-built data coherency.
- Channel by channel programmable sampling time.
- Discontinuous mode.
- Dual/Triple mode (with ADC1 and ADC2 or all 3 ADCs).
- DMA capability
- Analog Watchdog on high and low thresholds.
- Interrupt generation on:
  - End of Conversion
  - End of Injected conversion
  - Analog watchdog
  - Overrun
- ADCCLK, up to 36MHz, taken from PCLK through a prescaler (Div2, Div4, Div6 and Div8).
- Programmable sample time for each channel (from 4 to 480 clock cycles)
- Total conversion Time = $T_{\text{Sampling}} + T_{\text{conversion}}$
- With Sample time= 3 cycles @ ADC_CLK = 36MHz $\rightarrow$ total conversion time is equal to:

<table>
<thead>
<tr>
<th>Resolution</th>
<th>$T_{\text{Conversion}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 bits</td>
<td>12 Cycles</td>
</tr>
<tr>
<td>10 bits</td>
<td>10 Cycles</td>
</tr>
<tr>
<td>8 bits</td>
<td>8 Cycles</td>
</tr>
<tr>
<td>6 bits</td>
<td>6 Cycles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>resolution</th>
<th>Total conversion Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 bits</td>
<td>$12 + 3 = 15$ cycles</td>
</tr>
<tr>
<td>10 bits</td>
<td>$10 + 3 = 13$ cycles</td>
</tr>
<tr>
<td>8 bits</td>
<td>$8 + 3 = 11$ cycles</td>
</tr>
<tr>
<td>6 bits</td>
<td>$6 + 3 = 9$ cycles</td>
</tr>
</tbody>
</table>
ADC Analog Watchdog

- 12-bit programmable analog watchdog low and high thresholds
- Enabled on one or all converted channels: one regular or/and injected channel, all injected or/and regular channels.
- Interrupt generation on low or high thresholds detection
ADC dual modes

- ADCs: ADC1 master and ADC2 slave, ADC3 is independently.
- The start of conversion is triggered alternately or simultaneously by the ADC1 master to the ADC2 slave depending on the mode selected.
- 6 ADC dual modes
ADC triple modes

- ADCs: ADC1 master, ADC2 and ADC3 slaves.
- The start of conversion is triggered alternately or simultaneously by the ADC1 master to the ADC2 and ADC3 slaves depending on the mode selected.
- 6 ADC Triple modes.
DAC Features

- Two DAC converters: one output channel for each one
- 8-bit or 12-bit monotonic output
- Left or right data alignment in 12-bit mode
- Synchronized update capability
- Noise-wave or Triangular-wave generation
- Dual DAC channel independent or simultaneous conversions
- 11 dual channel modes
- DMA capability for each channel
- External triggers for conversion
- DAC supply requirement: 1.8V to 3.6 V
- Conversion range: 0 to 3.6 V
- DAC outputs range: \( 0 \leq \text{DAC\_OUT}_x \leq \text{VREF}^+ \) (\text{VREF}^+ is available only in 100, 144 and 176 pins package)
Timers on STM32F4

On board there are following timers available:

- **2x advanced 16bit** timers (TIM1,8)
- **2x general purpose 32bit** timers (TIM2,5)
- **8x general purpose 16bit** timers (TIM3,4,9,10..14)
- **2x simple 16bit** timers for DAC (TIM6,7)
- **1x 24bit system timer** (SysTick)
General Purpose timer Features overview

- TIM2, 3, 4 and 5 on Low Speed APB (APB1)
- Internal clock up to **84 MHz** (if AHB/APB1 prescaler distinct from 1)
- 16-bit Counter for TIM3 and 4
- 32-bit Counter for TIM2 and 5
  - Up, down and centered counting modes
  - Auto Reload
- 4 x 16 High resolution Capture Compare Channels
  - Programmable direction of the channel: input/output
  - Output Compare
  - PWM
  - Input Capture, PWM Input Capture
  - One Pulse Mode
- Synchronization
  - Timer Master/Slave
  - Synchronisation with external trigger
  - Triggered or gated mode
- Encoder interface
- 6 Independent IRQ/DMA Requests generation
  - At each Update Event
  - At each Capture Compare Events
  - At each Input Trigger
Advanced timer Features overview

- TIM1 and TIM8 on High Speed APB (APB2)
- Internal clock up to **168 MHz** (if AHB/APB2 prescaler distinct from 1)
- 16-bit Counter
  - Up, down and centered counting modes
  - Auto Reload
- 4 x 16 High resolution Capture Channels
  - Output Compare
  - PWM
  - Input Capture, PWM input Capture
  - One Pulse Mode
- 6 Complementary outputs: Channel1, 2 and 3
- Output Idle state selection independently for each output
- Polarity selection independently for each output
- Programmable PWM repetition counter
- Hall sensor interface
- Encoder interface
- 8 Independent IRQ/DMA Requests Generation
  - At each Update Event
  - At each Capture Compare Events
  - At each Trigger Input Event
  - At each Break Event
  - At each Capture Compare Update
- Embedded Safety features
  - Break input
  - Lockable unit configuration: 3 possible Lock level.
General Purpose 2 Channels timer (TIM9 & TIM12) Features overview

- TIM9 on High speed APB (APB2) and TIM12 on Low Speed APB (APB1)
- Internal clock up to **168 MHz** and **84 MHz** respectively
- 16-bit Counter
  - Up counting mode
  - Auto Reload
- 2 x 16 High resolution Capture Compare Channels
  - Programmable direction of the channel: input/output
  - Output Compare
  - PWM
  - Input Capture, PWM Input Capture
  - One Pulse Mode
- Synchronization Timer Master/Slave
  - Synchronization with external trigger
  - Triggered or gated mode
- Independent IRQ Requests generation
  - At each Update Event
  - At each Capture Compare Events
  - At each Input Trigger
General Purpose 1 Channels timer (TIM10..11 & TIM13..14) Features overview

- TIM10..11 on High speed APB (APB2) and TIM13..14 on Low Speed APB (APB1)
- Internal clock up to 168 MHz for TIM10/11
- Internal clock up to 84 MHz for TIM13/14
- 16-bit Counter
  - Up counting mode
  - Auto Reload
- 2 x 16 High resolution Capture Compare Channels
  - Programmable direction of the channel: input/output
  - Output Compare
  - PWM
  - Input Capture
- Independent IRQ Requests generation
  - At each Update Event
  - At each Capture Compare Events
- Cascade mode:
  - TIM_A used as master timer for TIM_B, TIM_B configured as TIM_A slave and master for TIM_C.
• One Master several slaves: TIM_A used as master for TIM_B, TIM_C and TIM_D.
Timers and external trigger synchronization

- TIM_A, TIM_B and TIM_C are slaves for an external signal connected to respective Timers inputs.

![Diagram of Timers and External Trigger](image-url)
<table>
<thead>
<tr>
<th>Feature Category</th>
<th>Counter resolution</th>
<th>Counter type</th>
<th>Prescaler factor</th>
<th>DMA</th>
<th>Capture Compare Channels</th>
<th>Complementary output</th>
<th>Synchronization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advanced TIM1 and TIM8</strong></td>
<td>16 bit</td>
<td>up, down and up/down</td>
<td>1..65536</td>
<td>YES</td>
<td>4</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td><strong>General purpose (1) TIM2 and TIM5</strong></td>
<td>32 bit</td>
<td>up, down and up/down</td>
<td>1..65536</td>
<td>YES</td>
<td>4</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td><strong>General purpose TIM3 and TIM4</strong></td>
<td>16 bit</td>
<td>up, down and up/down</td>
<td>1..65536</td>
<td>YES</td>
<td>4</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Basics TIM6 and TIM7</strong></td>
<td>16 bit</td>
<td>up</td>
<td>1..65536</td>
<td>YES</td>
<td>0</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td><strong>1 Channel (2) TIM10..11 and TIM13..14 (2)</strong></td>
<td>16 bit</td>
<td>up</td>
<td>1..65536</td>
<td>NO</td>
<td>1</td>
<td>0</td>
<td>YES (OC signal)</td>
</tr>
<tr>
<td><strong>2 Channel(2) TIM9 and TIM12</strong></td>
<td>16 bit</td>
<td>up</td>
<td>1..65536</td>
<td>NO</td>
<td>2</td>
<td>0</td>
<td>NO</td>
</tr>
</tbody>
</table>

(1) Same as STM32F2xx 32-Bit Timers
(2) These Timers are identical to STM32F2xx and STM32F1 XL Timers
## STM32F4xx Timer features overview 2/2

<table>
<thead>
<tr>
<th>Counter clock source</th>
<th>Output Compare</th>
<th>PWM</th>
<th>Input Capture</th>
<th>PWMI</th>
<th>OPM</th>
<th>Encoder interface</th>
<th>Hall sensor interface</th>
<th>XOR Input</th>
</tr>
</thead>
</table>
| **Advanced**
TIM1 and TIM8
- Internal clock APB2
- External clock:
  ETR/TI1/TI2/TI3/TI4 pins
- Internal Trigger:
  ITR1/ITR2/ITR3/ITR4
- Slave mode |
| 7 | 7 | 4 | 2 | 2 | Yes | Yes | Yes |
| **General Purpose**
TIM2 and TIM5
- Internal clock APB1
- External clock:
  ETR/TI1/TI2/TI3/TI4 pins
- Internal Trigger:
  ITR1/ITR2/ITR3/ITR4
- Slave mode |
| 4 | 4 | 4 | 2 | 2 | Yes | No | Yes |
| **General Purpose**
TIM3 and TIM4
- Internal clock APB1
- External clock:
  ETR/TI1/TI2/TI3/TI4 pins
- Internal Trigger:
  ITR1/ITR2/ITR3/ITR4
- Slave mode |
| 4 | 4 | 4 | 2 | 2 | Yes | No | Yes |
| **Basics**
TIM6 and TIM7
- Internal clock APB1 |
| No | No | No | No | No | No | No | No |
| **1 Channel**
TIM10/T1 and 13/14
- Internal clock APB1/APB2 |
| 1 | 1 | 1 | No | No | No | No | No |
| **2 Channel**
TIM9 and TIM12
- Internal clock APB1/APB2
- External clock: TI1/TI2/TI3/TI4 pins
- Internal Trigger:
  ITR1/ITR2/ITR3/ITR4
- Slave mode |
| 2 | 2 | 2 | 2 | 2 | No | No | No |
RTC Features

- Ultra-low power battery supply current < 1uA with RTC ON.
- Calendar with sub seconds, seconds, minutes, hours, week day, date, month, and year.
- Daylight saving compensation programmable by software
- Two programmable alarms with interrupt function. The alarms can be triggered by any combination of the calendar fields.
- A periodic flag triggering an automatic wakeup interrupt. This flag is issued by a 16-bit auto-reload timer with programmable resolution. This timer is also called ‘wakeup timer’.
- A second clock source (50 or 60Hz) can be used to update the calendar.
- Maskable interrupts/events:
  - Alarm A, Alarm B, Wakeup interrupt, Time-stamp, Tamper detection
- Digital calibration circuit (periodic counter correction) to achieve 5 ppm accuracy
- Time-stamp function for event saving with sub second precision (1 event)
- 20 backup registers (80 bytes) which are reset when an tamper detection event occurs.
STM32F4

Communication peripherals
Communication Peripherals

INTER-INTEGRATED CIRCUIT INTERFACE (I²C)

Same as STM32F-2
I²C Features (1/2)

- Multi Master and slave capability
- Controls all I²C bus specific sequencing, protocol, arbitration and timing
- Standard and fast I²C mode (up to 400kHz)
- 7-bit and 10-bit addressing modes
- Dual Addressing Capability to acknowledge 2 slave addresses
- Status flags:
  - Transmitter/Receiver mode flag
  - End-of-Byte transmission flag
  - I²C busy flag
- Configurable PEC (Packet Error Checking) Generation or Verification:
  - PEC value can be transmitted as last byte in Tx mode
  - PEC error checking for last received byte
I²C Features (2/2)

- Error flags:
  - Arbitration lost condition for master mode
  - Acknowledgement failure after address/ data transmission
  - Detection of misplaced start or stop condition
  - Overrun/Underrun if clock stretching is disabled

- 2 Interrupt vectors:
  - 1 Interrupt for successful address/ data communication
  - 1 Interrupt for error condition

- 1-byte buffer with DMA capability
- SMBus 2.0 Compatibility
- PMBus Compatibility
UNIVERSAL SYNCHRONOUS ASYNCHRONOUS RECEIVER TRANSMITTER (USART)

Same as STM32F-2

Communication Peripherals
USART Features (1/2)

- **6 USARTs**: USART1 & USART6 on APB2 and USART2,3,4,5 on APB1
- Fully-programmable serial interface characteristics:
  - Data can be 8 or 9 bits
  - Even, odd or no-parity bit generation and detection
  - 0.5, 1, 1.5 or 2 stop bit generation
  - **Oversampling by 16 (default) or by 8**
  - Programmable baud rate generator
    - Integer part (12 bits)
    - Fractional part (4 bits)
    - Baud rate for standard USART (SPI mode included)
      \[ Tx/Rx \text{ baud} = \frac{fck}{8 \times (2 - OVR8) \times USARTDIV} \]
      - Where:
        - **Tx/Rx baud**: desired baudrate
        - **OVR8**: oversampling by 8 (1 if enabled, 0 if disabled)
        - **fck**: APB frequency
        - **USARTDIV**: value to be programmed to the BRR register

Up to 10.5 Mbps
USART Features (2/2)

- Support hardware flow control (CTS and RTS)
- Dedicated transmission and reception flags (TxE and RxNE) with interrupt capability
- Support for DMA
  - Receive DMA request and Transmit DMA request
- 10 interrupt sources to ease software implementation
- LIN Master/Slave compatible
- Synchronous Mode: Master mode only
- IrDA SIR Encoder Decoder
- Smartcard Capability
- Single wire Half Duplex Communication
- Multi-Processor communication
  - USART can enter Mute mode
  - Mute mode: disable receive interrupts until next header detected
  - Wake up from mute mode (by idle line detection or address mark detection)
- Support One Sample Bit method: allows to disable noise detection (for noise-free applications) in order to increase the receiver’s tolerance to clock deviations.

Clock deviation tolerance up to 4.375%
SERIAL PERIPHERAL INTERFACE (SPI)

Communication Peripherals

Same as STM32F-2
SPI Features (1/2)

- **Up to 3 SPIs:** SPI1 on high speed APB2 and SPI2, SPI2 on low speed APB1
- **SPI2, SPI3 can work as SPI or I²S interface**
- Full duplex synchronous transfers on 3 lines
- Simplex synchronous transfers on 2 lines with or without a bi-directional data line
- Programmable data frame size: 8- or 16-bit transfer frame format selection
- Programmable data order with MSB-first or LSB-first shifting
- Master or slave operation
- Programmable **bit rate:** up to 37.5 MHz in Master/Slave mode
- NSS management by hardware or software for both master and slave: Dynamic change of Master/Slave operations
- **Motorola / TI mode** (master and slave operations).
SPI Features (2/2)

- Programmable clock polarity and phase
- Dedicated transmission and reception flags (Tx buffer Empty and Rx buffer Not Empty) with interrupt capability
- SPI bus busy status flag
- Master mode fault and overrun flags with interrupt capability
- Hardware CRC feature for reliable communication (CRC8, CRC16)
- Support for DMA
- Each SPI has a DMA Tx and Rx requests
- Each of the SPIs requests is mapped on a different DMA Stream: possibility to use DMA for all SPIs transfer direction at the same time
- Calculated CRC value is automatically transmitted at the end of data transfer
**I²S Features (1/2)**

- Two I²Ss: Available on SPI2 and SPI3 peripherals.
- Two I²Ss extension added for Full-Duplex communication.
- Dedicated PLL for high quality audio clock generation.
- Simplex/or Full duplex communication (transmitter and receiver)
- Can operate in master or slave configuration.
- 8-bit programmable linear prescaler to support all standard audio sample frequencies up to 192KHz.
- Programmable data format (16-, 24- or 32-bit data formats)
- Programmable packet frame (16-bit and 32-bit packet frames).
- Underrun flag in slave transmit mode, Overrun flag in receive mode and new de-synchronization flag in slave transmit/receive mode.
- 16-bit register for transmission and reception.
- Support for DMA (16-bit wide).
I²S Features (2/2)

- I²S protocols supported:
  - I²S Phillips standard.
  - MSB Justified standard (Left Justified).
  - LSB Justified standard (Right Justified).
  - PCM standard (with short and long frame synchronization on 16-bit channel frame or 16-bit data frame extended to 32-bit channel frame)

- Master clock may be output to drive an external audio component. Ratio is fixed at 256xFs (where Fs is the audio sampling frequency).

- **Note:** Since some SPI3/I²S3 pins are shared with JTAG pins, they are not controlled by the I/O controller and are reserved for JTAG usage (after each Reset). Prior to configure these pins, the user has to disable the JTAG and use the SWD interface (when debugging the application), or disable both JTAG/SWD interfaces (for standalone application).
Communication Peripherals

SD/SDIO MMC CARD HOST INTERFACE (SDIO)

Same as STM32F-2
SDIO Features

- Cards Clock Management: Rising and Falling edge, 8-bit prescaler, bypass, power save..
- **Hardware Flow Control**: to avoid FIFO underrun (TX mode) and overrun (RX mode) errors.
- A 32-bit wide, 32-word FIFO for Transmit and Receive
- DMA Transfer Capability
- Data Transfer: Configurable mode (Block or Stream), configurable data block size from 1 to 16384 bytes, configurable TimeOut
- 24 interrupt sources to ease software implementation
- CRC Check and generation
- SD I/O mode: SD I/O Interrupt, suspend/resume and Read Wait
- Data transfer up to 48 MHz
The SDIO consists of two parts:

- The SDIO adapter block provides all functions specific to the MMC/SD/SD I/O card such as the clock generation unit, command and data transfer.
- The APB2 interface accesses the SDIO adapter registers, and generates interrupt and DMA request signals.
SD/SDIO & MMC Cards

- The SDIO has 10 pins to control different kinds of memory cards
  - Only 6 pins (SDIO_CMD, SDIO_CK, SDIO_D[3:0]) at *most* for **SD cards** (SD full size, miniSD, microSD)
  - Only 6 pins (SDIO_CMD, SDIO_CK, SDIO_D[3:0]) at *most* for **SDIO cards** (SD full size, miniSD, microSD)
  - 10 pins (SDIO_CMD, SDIO_CK, SDIO_D[7:0]) at *most* for **MMC cards** (MMC full size, RS-MMC, MMC+ and MMCMobile)
FLEXIBLE STATIC MEMORY CONTROLLER (FSMC)

Same as STM32F-2
FSMC Features

The Flexible Static Memory Controller has the following main features:

- **4 Banks** to support External memory
- FSMC external access frequency is **84MHz when HCLK is at 168Hz**
- Independent chip select control for each memory bank
- Independent configuration for each memory bank
- Interfaces with static memory-mapped devices including:
  - static random access memory (SRAM)
  - read-only memory (ROM)
  - NOR/ OneNAND Flash memory
  - PSRAM
- Interfaces parallel LCD modules: Intel 8080 and Motorola 6800
- Supports burst mode access to synchronous devices (NOR Flash and PSRAM)
- NAND Flash and 16-bit PC Cards
  - With ECC hardware up to 8 Kbyte for NAND memory
  - 3 possible interrupt sources (Level, Rising edge and falling edge)
- Programmable timings to support a wide range of devices
- External asynchronous wait control
- Enhanced performance vs. STM32F10x
The FSMC consists of four main blocks:

- The AHB interface (including the IP configuration registers)
- The NOR Flash/PSRAM controller
- The NAND Flash/PC Card controller
- The external devices interface
FSMC Bank memory mapping

- For the FSMC, the external memory is divided into 4 fixed size banks of 4x64 MB each:
  - Bank 1 can be used to address NOR Flash, OneNAND or PSRAM memory devices.
  - Banks 2 and 3 can be used to address NAND Flash devices.
  - Bank 4 can be used to address a PC Card device.
USB 2.0 ON-THE-GO FULL SPEED (OTG FS)

Same as STM32F-2

Communication Peripherals
General Features

- Fully compliant with **Universal Serial Bus Revision 2.0** specification
- Dual Role Device (DRD) controller that supports both device and host functions compliant with **On-The-Go (OTG) Supplement Revision 1.3**
- Can be configured as host-only or device-only controller
- **Integrated PHY** with full support of the OTG mode
- Full-speed (12 Mbits/s) and low-speed (1.5 Mbits/s) operation (only full speed for device)
- **Dedicated RAM of 1.25 kB** with advanced FIFO management and dynamic memory allocation
Device Mode Features

- 1 bidirectional control endpoint0
- Up to 3 IN and 3 OUT endpoints configurable to support Bulk, Interrupt or Isochronous mode
- Shared RxFIFO for OUT endpoints
- Dedicated TxFIFO for each IN endpoint
- FIFO management with multi-packet transfer support
- Soft disconnection feature (removing internal D+ pull-up)
- USB suspend/resume with exit from STOP mode
Host Mode Features

- Up to 8 host channels (pipes) dynamically reconfigurable to any type of USB transfer
- Shared RxFIFO for IN channels
- Shared periodic TxFIFO for interrupt and isochronous OUT channels
- Shared non-periodic TxFIFO for bulk and control OUT channels
- Separate queue management for periodic and non-periodic transfer requests with up to 8 requests for each queue
- Built-in hardware scheduler for giving priority to periodic transfers request over non-periodic transfers requests
- FIFO management with Multi-packet transfer support
Embedded Full-speed OTG PHY Features

- FS/LS transceiver module used for Host/Device operation
- ID line detection for A/B device identification in OTG mode
- DP/DM integrated pull-up/pull-down resistors controlled by the USB core for device/host operation
- Vbus sensing and pulsing used for Session Request Protocol (SRP) in OTG mode
Hardware connections

Host-only Operation

Device-only Operation

Dual role OTG (Host/Device) Operation
USB 2.0 ON-THE-GO HIGH SPEED (OTG HS)
Main Features

- Fully compatible (@ register level) with the full-speed USB OTG peripheral

- High-speed (480 Mbit/s), full-speed and low speed operation in host mode and High-speed/Full-speed in device mode

- Three PHY interfacing options
  - Internal full-speed PHY (as for FS peripheral)
  - I2C interface for full-speed I2C PHY
  - ULPI bus interface for high-speed PHY

- DMA support with a dedicated FIFO of 4Kbytes
Device mode Features

- Same as Full-speed mode with some extended/new features:
  - Up to 5 IN bulk, interrupt or isochronous endpoints (Vs 3 in FS)
  - Up to 5 OUT bulk, interrupt or isochronous endpoints (Vs 3 in FS)
  - Separate NVIC interrupt vector for EP1_IN
  - Separate NVIC interrupt vector for EP1_OUT

- NYET handshake sending
  - In High Speed mode, after receiving a packet, the core sends NYET handshake if it does not find threshold amount of free space available in the RxFIFO
Host mode features

- Same as Full-speed mode features
  - Up to 12 channels (Vs 8 channels in FS peripheral)

- High-speed protocol specific features
  - **PING protocol**: when a HS device is not ready to accept new packet, it sends the NYET or NAK handshake, in this case the host shouldn’t continue data sending, but it should start the PING protocol to check periodically if device is ready to resume operation

  - **SPLIT protocol**: when the host is connected to a HS HUB, on which is connected a full/low speed device, the host will not wait response from the device, but it can do other HS transactions then after a period of time return to check if HS HUB has received any response from device

  - **Multi-transaction** during one micro-frame (125us) on isochronous transfers using (DATA0, DATA1, DATA2 and MDATA data PID)
ULPI High Speed PHY connection
USB High-Speed DMA features overview

- User can enable or disable the DMA mode
- The USB High-Speed DMA is connected to system bus matrix, it can support Burst transfers to/from SRAM or FSMC
- DMA can be enabled with or without FIFO thresholding
  - When FIFO thresholding is enabled a FIFO Rx/Tx levels can be configured to trigger DMA data transfer from RxFIFO to application buffer or from FIFO to USB bus
  - When FIFO thresholding is disabled, the trigger level is fixed to max packet size
- In DMA mode, as part of the transfer configuration parameters, application should program:
  - The application buffer destination address for OUT endpoints/IN channels
  - The application buffer source address for IN endpoints/OUT channels
- When DMA is enabled, a full transfer will be handled by DMA without CPU intervention for copying data to/from FIFOs
  - No more need for interrupts needed for FIFO management (TXFIFO empty interrupt, RxFIFO level interrupt)
Same as STM32F-2

Communication Peripherals

ETHERNET MAC 10/100
Main Features

- Supports 10/100Mbits Half/Full-duplex operations modes
- MII/RMII PHY interface
- Several options for MAC address filtering
- IPv4 checksum offload during receive and transmit operation
- **Dedicated DMA controller** with two FIFOs (Rx/Tx) of 2KBytes each
  - Connected as AHB master to system bus matrix
- Ethernet Time Stamping support - IEEE1588 version 2
- Power management: Wake on LAN with Magic Packet or Wakeup frame
- MAC management Counters for statistics
- MII loopback mode for debug purpose
Ethernet Block Diagram

- MMC: MAC Management Counters
- PMT: Power Management
- PTP: Precision Time Protocol
- RMII: Reduced MII
- MII: Media Independent Interface
Physical Layer Interface

- Supports both Media Independent Interface (MII) and Reduced Media Independent Interface (RMII)
- RMII is a lower pin count alternative, which targets multi-port applications and low cost design
  - **MII** = 16 pins (8 data and 8 control)
  - **RMII** = 7 pins (4 data and 3 control)
MAC FIFOs

- Two modes for data transfer between FIFOs and SRAM:
  - Threshold mode
  - Store and forward mode

- Threshold mode
  - During frame transmission as soon as the TXFIFO level crosses a defined FIFO level (default is 64 bytes), the data start to be pushed to MAC for frame transmission
  - During frame reception as soon as the RXFIFO level crosses a defined FIFO level (default is 64 bytes), the DMA start to transmit the data to SRAM

- Store and forward mode
  - A full frame should be available in TX or RXFIFO before transfer to MAC or SRAM
COMMUNICATION PERIPHERALS

CONTROLLER AREA NETWORK (BXCAN)

Same as STM32F-2
CAN Features

- **Dual CAN** 2.0 A, B Active w/ Bit rates up to 1Mbit/s, mapped on APB1
- Support time Triggered Communication
- Three transmit mailboxes w/ configurable transmit priority
- Two receive FIFOs with three stages and 28 filter banks shared between CAN1 and CAN2
- Time Stamp on SOF reception and transmission
- Maskable interrupts for easy software management
- Software efficient mailbox mapping at a unique address space
- 4 dedicated interrupt vectors: transmit interrupt, FIFO0 interrupt, FIFO1 interrupt and status change error interrupt
- The two CAN cells share a dedicated 512-byte SRAM memory and capable to work simultaneously with USB OTG FS peripheral
- **CAN1**: Master bxCAN manage the communication between a Slave bxCAN and the 512-byte SRAM memory.
- **CAN2**: Slave bxCAN start filter bank number n[27:1] is configurable by SW.
DIGITAL CAMERA INTERFACE (DCMI)

Same as STM32F-2
DCMI Features

- The Digital Camera Interface has the following main features:
  - 8-, 10-, 12- or 14-bit parallel interface
  - Continuous or snapshot mode
  - Crop feature
  - Supports the following data formats:
    - 8/10/12/14-bit progressive scan: either monochrome or raw bayer
    - YCbCr 4:2:2 progressive scan
    - RGB 565 progressive video
    - Compressed data: JPEG

- With a 48MHz PIXCLK and 8-bit parallel input data interface it is possible to receive:
  - up to 15fps uncompressed data stream in SXGA resolution (1280x1024) with 16-bit per pixel
  - up to 30fps uncompressed data stream in VGA resolution (640x480) with 16-bit per pixel
DCMI Data transfer

- The data are packed into a 32-bit data register (DCMI_DR) connected to the AHB bus
- 8x32-bit FIFO with DMA handling.
**DCMI CROP feature**

- The DCMI interface supports two types of capture:
  - The DCMI can select a rectangular window from the received image
  - The start coordinates and size are specified using two 32-bit registers DCMI_CWSTRT and DCMI_CWSIZE.
- The size of the window is specified in number of pixel clocks (horizontal dimension) and in number of lines (vertical dimension)
CRYPTOGRAPHIC PROCESSOR (CRYP)

Same as STM32F-2
Definitions

- **AES**: Advanced Encryption Standard
- **DES**: Data Encryption Standard
- **TDES**: Triple Data Encryption Standard

Encryption/Decryption modes

- **ECB**: Electronic code book mode
- **CBC**: Cipher block chaining mode or chained encryption
- **CTR**: Counter mode (used for GCM: Galois Counter Mode)

  GCM is a combination of CTR and GHASH.
## CRYP algorithms overview

<table>
<thead>
<tr>
<th></th>
<th>AES</th>
<th>DES</th>
<th>TDES</th>
</tr>
</thead>
</table>
| **Key sizes**        | 128, 192 or 256 bits         | 64\* bits 8 parity bits     | 192***, 128** or 64\* bits 8 parity bits: Keying option 1  
                        |                              |                              | ** 16 parity bits: Keying option 2  
                        |                              |                              | ***24 parity bits: Keying option 3 |
| **Block sizes**      | 128 bits                     | 64 bits                      | 64 bits                       |
| **Time to process one block** | 14 HCLK cycle for key = 128bits  
                      | 16 HCLK cycle for key = 192bits  
                      | 18 HCLK cycle for key = 256bits  | 16 HCLK cycles               
                        | 16 HCLK cycles               | 48 HCLK cycles               |
| **Type**             | block cipher                 | block cipher                 | block cipher                  |
| **Structure**        | Substitution-permutation network  | Feistel network               | Feistel network               |

- AES: Advanced Encryption Standard
- DES: Data Encryption Standard
- TDES: Triple Data Encryption Standard
CRYP Features (1/2)

- Suitable for AES, DES and TDES enciphering and deciphering operations
- Runs at the same frequency as the CPU, up to 168 MHz.

**DES/TDES**
- Direct implementation of simple DES algorithms (a single key, K1, is used)
- Supports the ECB and CBC chaining algorithms
- Supports 64-, 128- and 192-bit keys (including parity)
- 64-bit initialization vectors (IV) used in the CBC mode
- 16 HCLK cycles to process one 64-bit block in DES
- 48 HCLK cycles to process one 64-bit block in TDES
CRYP Features (2/2)

- **AES**
  - Supports the ECB, CBC and CTR chaining algorithms
  - Supports 128-, 192- and 256-bit keys
  - 128-bit initialization vectors (IV) used in the CBC and CTR modes
  - 14, 16 or 18 HCLK cycles (depending on the key size) to transform one 128-bit block in AES

- **Common to DES/TDES and AES**
  - IN and OUT FIFO (each with an 8-word depth, a 32-bit width, corresponding to 4 DES blocks or 2 AES blocks)
  - Automatic data flow control with support of direct memory access (DMA) (using 2 channels, one for incoming data the other for processed data)
  - Data swapping logic to support 1-, 8-, 16- or 32-bit data
ECB Encryption

- The simplest of the encryption modes is the **Electronic codebook** (ECB) mode. The message is divided into blocks and each block is encrypted separately.

- The disadvantage of this method is that identical plaintext blocks are encrypted into identical cipher text blocks; thus, it does not hide data patterns well. To avoid this weakness, CBC or CTR modes can be used.
Cipher block chaining mode (CBC)

- CBC mode of operation was invented by IBM in 1976.
- In the CBC mode, each block of plaintext is XORed with the previous cipher text block before being encrypted.
- This way, each cipher text block is dependent on all plaintext blocks processed up to that point.
- To make each message unique, an initialization vector must be used in the first block.
Counter mode (CTR): AES only

- Counter mode turns a block cipher into a stream cipher. It generates the next key stream block by encrypting successive values of a "counter".
- The counter can be any function which produces a sequence which is guaranteed not to repeat for a long time, although an actual counter is the simplest and most popular.
- CTR mode is well suited to operation on a multi-processor machine where blocks can be encrypted in parallel.
- The IV/nonce and the counter can be concatenated, added, or XORed together to produce the actual unique counter block for encryption.
<table>
<thead>
<tr>
<th></th>
<th>AES-128</th>
<th>AES-192</th>
<th>AES-256</th>
<th>DES</th>
<th>TDES</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW Theoretical</td>
<td>192.00</td>
<td>168.00</td>
<td>149.33</td>
<td>84.00</td>
<td>28.00</td>
</tr>
<tr>
<td>HW Without DMA</td>
<td>72.64</td>
<td>72.64</td>
<td>62.51</td>
<td>43.35</td>
<td>16.00</td>
</tr>
<tr>
<td>HW With DMA</td>
<td>128.00</td>
<td>168.00</td>
<td>149.33</td>
<td>84.00</td>
<td>28.00</td>
</tr>
<tr>
<td>Pure SW</td>
<td>1.38</td>
<td>1.14</td>
<td>0.96</td>
<td>0.74</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Throughput in MB/s at 168 MHz for the various algorithms and implementations.
The cryptographic processor provides an interface to connect to the DMA controller. The DMA operation is controlled through the CRYP DMA control register, CRYP_DMACR.

2 requests are available
- Request DMA for outgoing data transfer from FIFO OUT
- Request DMA for incoming data transfer to FIFO IN

All request signals are de-asserted if the CRYP peripheral is disabled or the DMA enable bit is cleared (DIEN bit for the IN FIFO and DOEN bit for the OUT FIFO in the CRYP_DMACR register).

**Important to know**
- The DMA controller must be configured to perform burst of 4 words or less. Otherwise some data could be lost.
- In order to let the DMA controller empty the OUT FIFO before filling up the IN FIFO, the OUTDMA Stream should have a higher priority than the INDMA Stream.
RANDOM NUMBER GENERATOR (RNG)

Same as STM32F-2
RNG Features

- 32-bit random numbers, produced by an analog generator (based on a continuous analog noise)
- Clocked by a dedicated clock (PLL48CLK)
- 40 periods of the PLL48CLK clock signal between two consecutive random numbers
- Can be disabled to reduce power-consumption
- Provide a success ratio of more than 85% to FIPS 140-2 (Federal Information Processing Standards Publication 140-2) tests for a sequence of 20 000 bits.

- 5 Flags
  - 1 flag occurs when Valid random Data is ready
  - 2 Flags to an abnormal sequence occurs on the seed.
  - 2 flags for frequency error (PLL48CLK clock is too low).

- 1 interrupt
  - To indicate an error (an abnormal sequence error or a frequency error)
RNG Block Diagram

RNG

- RNG_CLK
- LFSR (Linear Feedback Shift register)
- Flags
  - Interrupt enable bit
  - IM
  - DRDY
  - SECS
  - SEIS
  - CECS
  - CEIS
- Error management
  - Clock checker
  - Fault detector
- Analog Seed
- 32bit random data register

RNG interrupt to NVIC
HASH PROCESSOR (HASH)

Same as STM32F-2
A **cryptographic hash function** is a deterministic procedure that takes an arbitrary block of data and returns a fixed-size bit string, the **(cryptographic) hash value**, such that an accidental or intentional change to the data will change the hash value. The data to be encoded is often called the "**message**", and the hash value is sometimes called the **message digest** or simply **digest**.
Definitions

- **SHA-1**: the Secure Hash algorithm

- **MD5**: Message-Digest algorithm 5 hash algorithm

- **HMAC**: (keyed-Hash Message Authentication Code) algorithm

- **HASH**: Computes a SHA-1 and MD5 message digest for messages of up to \(2^{64} - 1\) bits

- HMAC algorithms provide a way of authenticating messages by means of hash functions.

- HMAC algorithms consist in calling the SHA-1 or MD5 hash function twice on message in combination with a secret value (key).
HASH Features

- Suitable for Integrity check and data authentication applications, compliant with:
  - FIPS PUB 180-2 (Federal Information Processing Standards Publication 180-2)
  - Secure Hash Standard specifications (SHA-1)
  - IETF RFC 1321 (Internet Engineering Task Force Request For Comments number 1321) specifications (MD5)

- AHB slave peripheral
- Fast computation of SHA-1 and MD5:
  - 66 HCLK clock cycles in SHA-1
  - 50 HCLK clock cycles in MD5

- $5 \times (32$-bit$)$ words (H0, H1, H2, H3 and H4) for output message digest, reload able to continue interrupted message digest computation
- Automatic data flow control with support for direct memory access (DMA)
- 32-bit data words for input data, supporting word, half-word, byte and bit bit-string representations, with little-endian data representation only
HASH Block Diagram

- **Input FIFO**: 16 x 32bit
- **Data swapping**
- **HASH Processor**
  - MD5
  - SHA-1
  - HMAC
- **Message Digest**: H0..H4, 5x32bit
- **Flags**
  - DINIS
  - BUSY
  - DMAS
  - DCIS
- **Flag**
  - DINIM
  - DCIM
- **HASH Global interrupt (NVIC)**
- **DMA request**

**Components**:
- **HASH**
- **Message Digest**
- **Input FIFO**
- **Data swapping**
- **HASH Processor**
- **Flags**
- **DMA request**
- **HASH Global interrupt (NVIC)**
HASH throughput

- Throughput in MB/s at 168 MHz for SHA-1 and MD5 algorithms with different implementations

<table>
<thead>
<tr>
<th></th>
<th>MD5</th>
<th>SHA1</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW Theoretical</td>
<td>162.9</td>
<td>131.12</td>
</tr>
<tr>
<td>HW Without DMA</td>
<td>77.35</td>
<td>71.68</td>
</tr>
<tr>
<td>HW With DMA</td>
<td>105.40</td>
<td>91.11</td>
</tr>
<tr>
<td>Pure SW</td>
<td>11.52</td>
<td>5.15</td>
</tr>
</tbody>
</table>
Thank you

www.st.com/stm32f4