Software Development Tools for Cortex-M4 Microcontrollers

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November 2010
Keil - MCU Tools from ARM

- Tailored to ARM Cortex™-M devices
  - Optimized Compiler, IDE, Debugger, and Debug/Trace Adapters
  - Support advanced Cortex-M and CoreSight technologies
  - RTOS and middleware optimized for Cortex-M3 and Cortex-M4

- Enable developers to:
  - Start projects faster
    - Device Database provides tool setup, start-up code, header files, flash algorithm, etc.
  - Write efficient DSP code
    - ARM Compiler optimized for Cortex-M4 SIMD instruction set
  - Verify and optimize software
    - ULINKpro with Streaming Trace provides Code Coverage and Performance Analyzer
Software Development Tools

Microcontroller Development Kit

Complete support for Cortex™-M, Cortex-R, and ARM7™/ARM9™ Devices

CMSIS COMPLIANT

ARM Cortex™ Microcontroller Software Interface Standard

MDK-ARM
Microcontroller Development Kit

ARM C/C++ Compiler
RTX RTOS
µVision
Device Database & IDE
µVision
Debugger & Analysis Tools
Device Peripheral Simulation

Examples and Templates

ULINK Debug Adapters

Debugger Run-Control
Debug Channel
Flash ROM
RAM
Real-Time Clock

ULINKPro

RTX and Real-Time Library

RTOS and middleware libraries for real-time and communication challenges

RTX RTOS Source Code
TCPnet Networking Suite
Flash File System
USB Device/Host/OTG
CAN Interface

Examples and Templates

The Architecture for the Digital World®
USING CORTEX-M4 FOR DIGITAL SIGNAL PROCESSING
Cortex MCU Software Standard

- Cortex Microcontroller Software Interface Standard (CMSIS)
  - Abstraction layer for all Cortex-M processor-based devices

- CMSIS 2.0: Cortex-M4 support for SIMD
- CMSIS-SVD: XML peripheral debug description

Benefits to the embedded developer
- Consistent software interfaces for silicon and middleware vendors
- Simplifies re-use across Cortex-M processor-based devices
- Reduces learning curve, development costs, and time-to-market
CMSIS DSP Library

- Collection of 61 algorithms
  - C Source Code, optimized for Cortex-M3 and Cortex-M4
  - For CMSIS compliant C Compilers (ARM/Keil, IAR, GCC)

- Basic Math Functions
  - Vector Multiplication
  - Vector Subtraction
  - Vector Addition
  - Vector Scale
  - Vector Shift
  - Vector Offset
  - Vector Negate
  - Vector Absolute
  - Vector Dot Product

- Fast Math Functions
  - Cosine
  - Sine
  - Square root of number

- Complex Math Functions
  - Complex conjugate
  - Complex dot product
  - Complex magnitude
  - Complex magnitude squared
  - Complex by complex multiplication
  - Complex by real multiplication

- Filters
  - Biquad Cascade IIR Filters Using Direct form I Structure
  - Finite Impulse Response (FIR) Filters
  - Convolution
  - Partial Convolution
  - Correlation
  - Finite Impulse Response (FIR) Decimation
  - Finite Impulse Response (FIR) Lattice Filters
  - Infinite Impulse Response (IIR) Lattice Filters
  - Biquad Cascade IIR 32x64 filter using Direct form I structure
  - Biquad Cascade IIR Filters Using a Direct form II Transposed Structure
  - Finite Impulse Response (FIR) Sparse Filters
  - Finite Impulse Response (FIR) Interpolation
  - Least Mean Square FIR Filter
  - Least Mean Square Normalized FIR Filter

- Matrix Functions
  - Matrix Addition
  - Matrix Initialization
  - Matrix Scale
  - Matrix Subtraction
  - Matrix Multiplication
  - Matrix Inverse
  - Matrix Transpose

- Transforms
  - Complex FFT Functions
  - Real FFT Functions
  - DCT Type IV Function

- Controller Functions
  - SineCosine
  - PID Motor Control
  - Vector park transform
  - Vector Inverse park transform
  - Vector Clarke transform
  - Vector Inverse Clarke transform

- Statistical Functions
  - Power
  - Root mean square (RMS)
  - Standard deviation
  - Variance
  - Maximum
  - Minimum
  - Mean

- Support Functions
  - Vector Copy
  - Vector Fill
  - Convert 8-bit Integer value
  - Convert 16-bit Integer value
  - Convert 32-bit Integer value
  - Convert 32-bit floating point value

- Interpolator Functions
  - Linear Interpolate Function
  - Bilinear Interpolate Function
DSP Library Performance

- Cortex-M4 SIMD + FPU
  - Fix point: ~2x faster
  - Floating point: ~10x faster

DSP Library Benchmark: Cortex-M3 vs. Cortex-M4

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Cortex-M3</th>
<th>Cortex-M4</th>
<th>Memory Access Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIR q15 fixed point</td>
<td>14,668</td>
<td>4,228</td>
<td>71%</td>
</tr>
<tr>
<td>PID q15 fixed point</td>
<td>1,908</td>
<td>1,040</td>
<td>45%</td>
</tr>
<tr>
<td>IIR q31 fixed point</td>
<td>10,345</td>
<td>6,948</td>
<td>33%</td>
</tr>
<tr>
<td>Matrix Mul fixed point</td>
<td>6,800</td>
<td>3,771</td>
<td>45%</td>
</tr>
<tr>
<td>Correlation floating point</td>
<td>168,031</td>
<td>15,235</td>
<td>91%</td>
</tr>
</tbody>
</table>

Cycles: smaller numbers are better

On Cortex-M4: uses SIMD & FPU instructions
DSP Data Handling

- Managing data flow: major challenge of DSP systems

- Analog signals sampled as discrete values
  - Each sample is a single value at a specific point in time
  - Sample rate must be >2x max analog frequency
  - Oversampling rates >4x max freq often used for better signal quality
    - for high-quality Audio = 96 KHz

- Challenge: handle and process samples in real-time
Stream vs. Block Processing

Stream Processing
- Process one sample at a time
  - Low signal delay
  - Lower memory requirements
- Complex DSP Processing in High-Priority Interrupt Routine
  - High Latency for other ISRs

Block Processing
- Process blocks of samples at a time
  - Signal delay due to data block buffering
- Enables DMA Data Collection
  - Reduces Interrupt Overhead
  - Easy to combine with RTOS

Block Processing: preferred for most applications
CMSIS DSP Library is designed for Block Processing
Block Processing

- Longer blocks (~32 samples) reduce overhead
  - Due to fewer ISR and function calls
- But – introduce signal delays proportional to block size

Signal Delay = 2 x BlockSize
RTX: Message + Mailbox System buffers processing peaks
- Interacts with Tasks or Interrupt Service Routines
- Keeps a system responsive even with high workload
SOFTWARE DEBUG, OPTIMIZATION AND VERIFICATION
CoreSight™ Debug Technology

- Start, Stop, and Single-step User Program
- Instruction Trace Stream
- Application Trace Information: Debug printf, ITM, DWT, ETM
- Data Trace or Access Breakpoints for 4 Variables
- ITM, DWT, ETM Output via 4 trace data pins + 1 clock pin

Cortex-M4 processor

- 8 Hardware Breakpoints
- On-the-Fly read/write access
- JTAG (5-pin) or Serial Wire (2-pin + 1 trace pin)

- Run Control
- Breakpoint Unit
- Memory Access Unit
- Debug Interface
- Serial Wire Viewer
- JTAG or Serial Wire Debug
- Cortex Debug 10-pin or ARM JTAG 20-pin Connector
- Cortex Debug + ETM 20-pin Connector (optional)

- ETM Instruction Trace (optional)
- ITM Instrumentation Trace
- DWT Data Watchpoint & Trace Unit
- CPU & Interrupt Events
- 4-Pin Trace
- Trace Port Interface
- ITM, DWT Output via 1 serial trace data pin (UART or Manchester Mode)

13 The Architecture for the Digital World®
**Debug and Trace Connectors**

- **20-pin (0.1”) or 10-pin (0.05”) Connector**
  - Identical Debugging capabilities

**Support 2 Operating Modes:**
- Standard 5-pin JTAG mode (device chaining)
- Serial CoreSight mode
  - 2-pin **Serial Wire Debug** (SWD)
  - 1-pin **Serial Wire Trace Output** (SWO) for Data Trace at minimum system cost

- **20-pin (0.05”) Debug+ETM Connector**
  - Superset of 10-pin 0.05” Connector
  - Adds 4 (trace data) +1 (trace clock) pins for high-speed Data + Instruction Trace in any operating mode (JTAG or SWD)

Debug and Trace Adapters

ULINK2: Debug + Serial Wire Trace
- Flash Programming + Run-Control
- Memory + Breakpoint (access while running)
- Serial Wire Trace Capturing up to 1Mbit/sec (UART mode)

ULINKpro: adds ETM + Streaming Trace
- Cortex-M processors running up to 200MHz
  - 50MHz JTAG clock speed
  - Serial Wire Trace Capturing up to 100Mbit/sec (Manchester Mode)
  - ETM Trace Capturing up to 800Mbit/sec
- Virtually un-limited Trace Buffer
  - Streaming Trace allows complete Code Coverage and Performance Analysis
What is Streaming Trace?

- Trace data transferred in real-time to debug host
- Capture size only limited by host resources (hard disk)
- Trace for minutes, hours, or longer
- Required for full code-coverage and timing analysis
- Today’s workstations can present trace data instantly
Logic Analyzer

- Allows signals to be monitored graphically
  - Monitor variables in the application
- Accurate timing
  - Easy, fast analysis of signal timing with access to source code
  - View delta changes from cursor to current location
- Code analysis
  - View instruction that caused variable change
Execution Time Profiling and Analysis

- Instruction Trace provides timing information
  - Identify where most time is spent in your application

- Isolate problems by finding which C statements take longer than expected to execute
Code Coverage

- Complete software validation requires code coverage
  - Required for industry standards such as IEC61508……..
- ETM enabled devices provide complete instruction stream
  - Non-intrusive - use final, optimized code at full speed
- Feedback provided directly in the debugger window
  - Source & disassembly view
- Log File Support
  - Coverage information can be saved for documentation
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- Application Notes
- Program Examples
- Device Database
- Support Knowledge
- Discussion Forum

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For any queries contact < Salesinfo-IN@arm.com >