



White paper

**System analysis and real-time tracing
with Serial Wire Viewer (SWV)**

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ABSTRACT

ARM® Cortex® microcontrollers continue to push the price/performance ratio to unprecedented levels. In addition, the inclusion of a subset of the CoreSight debug architecture in these device families improves debugging capabilities substantially without incurring excessive cost. It is now possible to have greater visibility into the dynamics of complex real-time embedded applications than ever before. This visibility is extremely useful not only in the increasingly complex applications typically found in today's products, but in applications that cannot be halted for the debugging process.

This white paper outlines how the Serial Wire viewer and associated technologies which are part of the CoreSight architecture can be used for advanced debugging while embedded applications execute at full speed.

INTRODUCTION

Finding bugs in software is a difficult and time consuming process. Debugging is usually more difficult in many embedded applications for several reasons. Execution timing is often critical, and results can be skewed by the inclusion of instrumentation code. In cases of motor, actuator or other control applications, it may not be possible, or particularly revealing to stop the device under test for debugging operations. In many applications, it is desirable to examine resources as the application executes in order to preserve synchronization of interrupts as well as internal or external events.

The Serial Wire Viewer (SWV) technology from ARM, found in Cortex-M microcontroller product families, provides real-time tracing and memory access with little or no processor overhead while the application executes at full speed. This is made possible by the internal architecture of the devices, and does not require software support such as low priority daemons or monitor code that must be linked with the application. The Instrumentation Trace Macro cell (ITM) is a minimally intrusive way to transmit data via one of the 32 ITM ports as the application executes. This enables printf() style debugging without a physical UART, USB, Ethernet or other type of communication channel.

This white paper gives a brief background to the Serial Wire Viewer (SWV) and Instrumentation Trace Macro cell (ITM) technology. It also outlines how advanced debuggers can exploit the SWV and ITM technology to deliver powerful debug capabilities to developers. Many embedded developers continue to use “tried and true” methods of debugging such as blinking LED and printf() outputs. When the ease of use, information content and the cost efficiency of modern debugging technology is considered, it is well worth a developer’s while to devote the relatively small amount of effort to becoming familiar with these methodologies as the payback in time savings in debugging and testing will be considerable.

SERIAL WIRE VIEWER OVERVIEW

To use system analysis and real-time tracing in compatible ARM processors, a number of different technologies interact; Serial Wire Viewer (SWV), Serial Wire Debug (SWD) and Serial Wire Output (SWO). Their respective roles will be explained below.

SERIAL WIRE DEBUG (SWD)

Serial Wire Debug (SWD) is a debug port similar to JTAG, and provides the same debug capabilities (run, stop on breakpoints, single-step) but with fewer pins. It replaces the JTAG connector with a 2-pin interface (one clock pin and one bi-directional data pin). The SWD port itself does not provide for real-time tracing.

SERIAL WIRE OUTPUT (SWO)

The Serial Wire Output (SWO) pin can be used in combination with SWD and is used by the processor to emit real-time trace data, thus extending the two SWD pins with a third pin. The combination of the two SWD pins and the SWO pin enables Serial Wire Viewer (SWV) real-time tracing in compatible ARM processors.

SERIAL WIRE VIEWER (SWV)

Serial Wire Viewer is a real-time trace technology that uses the Serial Wire Debugger (SWD) port and the Serial Wire Output (SWO) pin. Serial Wire Viewer provides advanced system analysis and real-time tracing without the need to halt the processor to extract certain types of debug information.

Serial Wire Viewer (SWV) can provide the following types of target information:

- Periodic samples of program counter (PC) values
- Event notification on memory accesses (such as reading/writing C variables)
- Event notification on exception entry and exit
- Event counters
- Timestamp and CPU cycle information

Based on this trace data, modern debuggers can provide developers with advanced debugger capabilities.

The developer can configure SWV in many different ways, to make it emit various combinations of information, e.g. values of memory locations, events, PC values etc. As more types of trace data are enabled for transmission, the more trace packages are needed to be sent from the CPU to the PC debugger. It is possible in certain circumstances that all of the data may not be received by the front end debugging software on the PC.

There are several reasons for this. The target CPU running at full speed can exceed bandwidth on the one-pin SWO output. In addition, trace data makes its way to the SWO via internal buffers which are limited in depth. If the CPU generates more trace packages than the SWO pin can transmit, there will be resulting packet loss. This is normal.

The reason is that Cortex-M microcontrollers are designed to meet aggressive cost targets. The resource limitation is a byproduct of the tradeoff between resources and cost, and is to some extent, “by design”. While this imposes minor limitations on what can be done, it is also true that SWV and ITM, used with care, are capable of providing very powerful debug information that in some cases are otherwise unobtainable information without very expensive debug hardware.

INSTRUMENTATION TRACE MACRO CELL (ITM)

The Instrumentation Trace Macro cell (ITM) enables applications to write arbitrary data to the SWO pin, which can then be interpreted and visualized in the debugger in various ways. For example, ITM can be used to redirect printf() output to a console view in the debugger.

This is highly desirable and useful for several reasons. First, the overhead is very low as a memory location can be transferred in a single clock cycle. Second, there is no requirement for an on-board resource such as a UART or USB connection, as the data is transmitted using the debug probe hardware. Third, the ITM port has 32 channels, and by writing different types of data to different ITM channels, the debugger can interpret or visualize the data on various channels differently.

Since writing a byte to the ITM port only takes one clock cycle, applications can thus keep the ITM trace instrumentation when the product ships. It is then not needed to rebuild and retest a product build with instrumentation removed. Leaving this kind of instrumentation in the shipped code also provides the capability of connecting a debugger to a live system in-the-field for detailed analysis in deployed products.

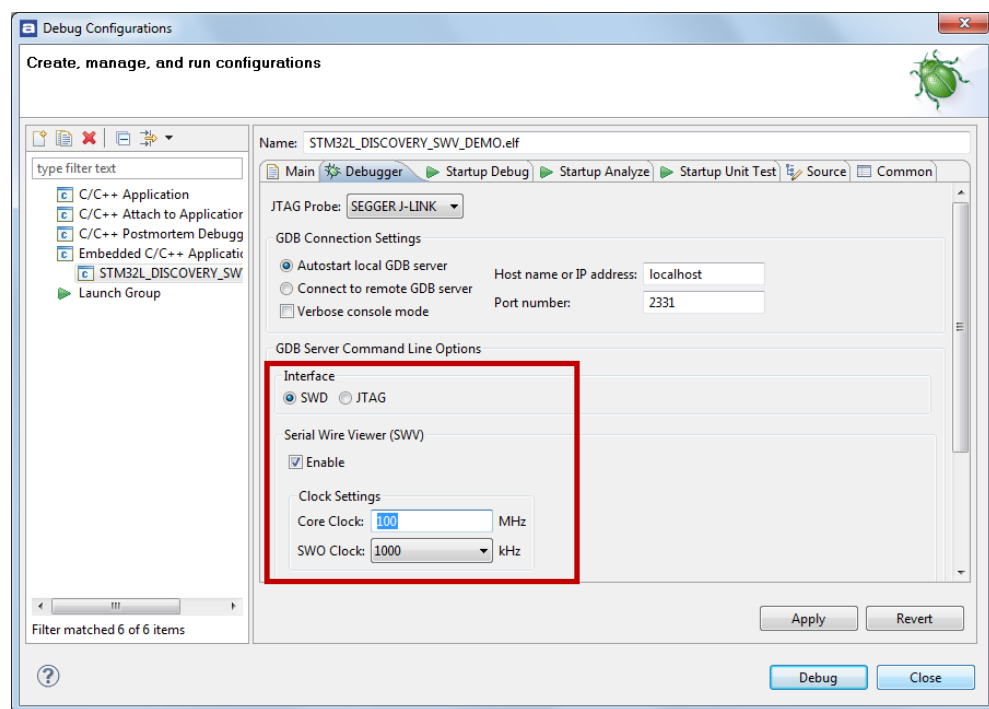
SYSTEM ANALYSIS AND REAL-TIME TRACING

Modern debuggers can exploit Serial Wire Viewer (SWV) to provide a number of advanced debugger capabilities to embedded developers. This section outlines some of the Serial Wire Viewer debugger features found in **Atollic TrueSTUDIO®** (compatible ARM targets only).

SWV TRACE CONFIGURATION

Serial Wire Viewer (SWV) can be enabled in the **Atollic TrueSTUDIO®** debug configuration dialog. To enable SWV, enable it by selecting the corresponding checkbox and select the CPU core clock frequency and desired SWO clock speed.

All JTAG probes do not support SWV. For example the first generation of ST-LINK does not, but the ST-LINK/V2 does. A SEGGER J-Link older than hardware version 6.0 does not. J-Link v6.0, v7.0 and v8.0 do support SWV.

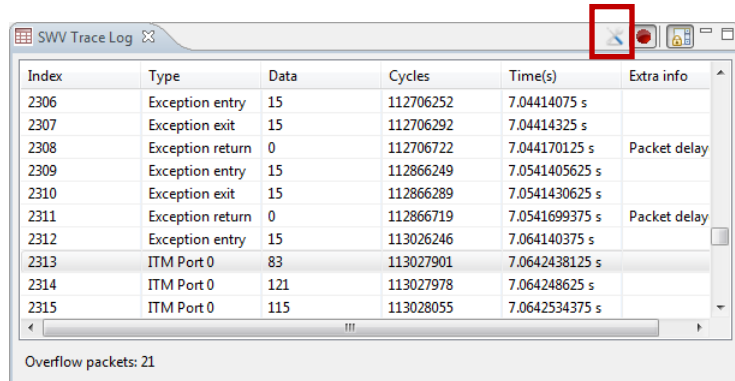


To make SWV work, it is important to make sure SWD mode is selected, SWV is enabled, and that the CPU core clock speed and SWO clock is configured correctly.

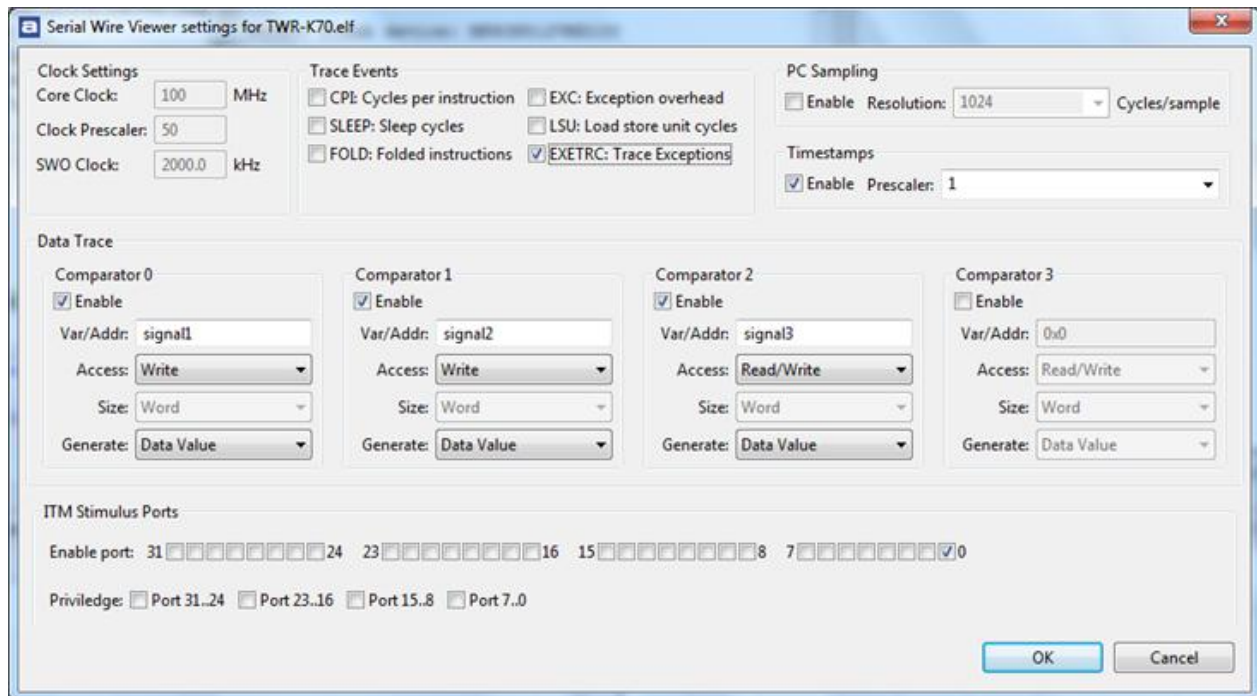
It is particularly important to note the SWD/JTAG radio buttons. Sometimes older projects provided by semiconductor manufacturers have JTAG set by default, and overlooking this is a sure way to disable SWV.

Once SWV has been enabled, a debug session can be started and execution runs to the first breakpoint, typically in the power-on-reset interrupt handler or the first line in the main() function.

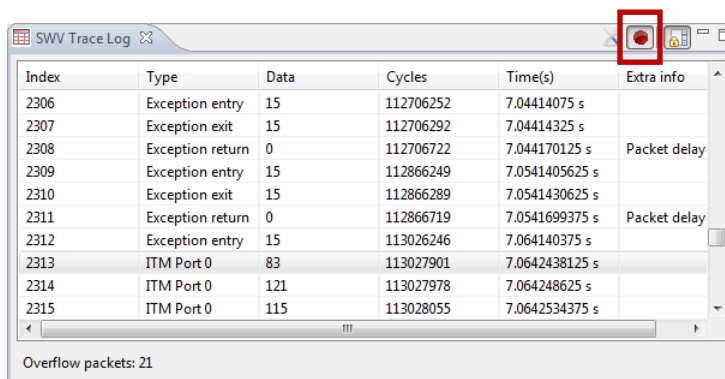
Configuration of the events that are to be captured is configured in the SWV Trace configuration dialog box. This dialog box is opened by clicking on the “hammer and wrench” toolbar button in any of the SWV docking views.



Once the SWV configuration dialog box is opened, the user is presented with a number of SWV trace settings:



When the desired SWV event packages have been selected, the trace record button must be activated to enable recording of trace records. This is done by clicking on the red “record” button. Seeing its display changed is the way it is shown to be activated.



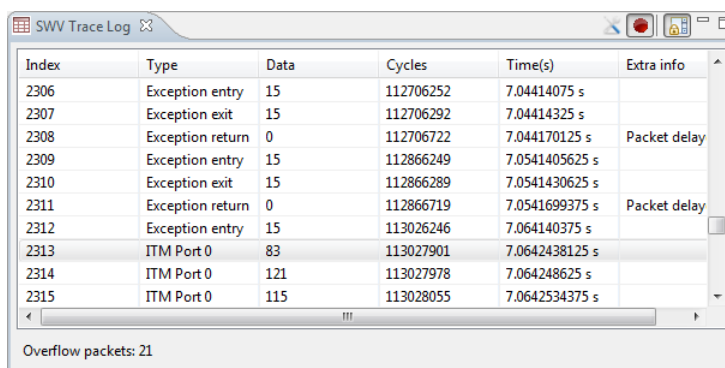
| Index | Type | Data | Cycles | Time(s) | Extra info |
|-------|------------------|------|-----------|----------------|--------------|
| 2306 | Exception entry | 15 | 112706252 | 7.04414075 s | |
| 2307 | Exception exit | 15 | 112706292 | 7.04414325 s | |
| 2308 | Exception return | 0 | 112706722 | 7.044170125 s | Packet delay |
| 2309 | Exception entry | 15 | 112866249 | 7.0541405625 s | |
| 2310 | Exception exit | 15 | 112866289 | 7.0541430625 s | |
| 2311 | Exception return | 0 | 112866719 | 7.0541699375 s | Packet delay |
| 2312 | Exception entry | 15 | 113026246 | 7.064140375 s | |
| 2313 | ITM Port 0 | 83 | 113027901 | 7.0642438125 s | |
| 2314 | ITM Port 0 | 121 | 113027978 | 7.064248625 s | |
| 2315 | ITM Port 0 | 115 | 113028055 | 7.0642534375 s | |

Overflow packets: 21

With serial wire viewer tracing now enabled and the desired event notification types configured, trace recording is activated. As the application executes, the debugger will receive SWV trace records from the processor via the debug probe, and the debugger software will update its trace views in real-time as long as target execution continues.

SWV TRACE LOG AND GRAPHICAL TIMELINE CHART

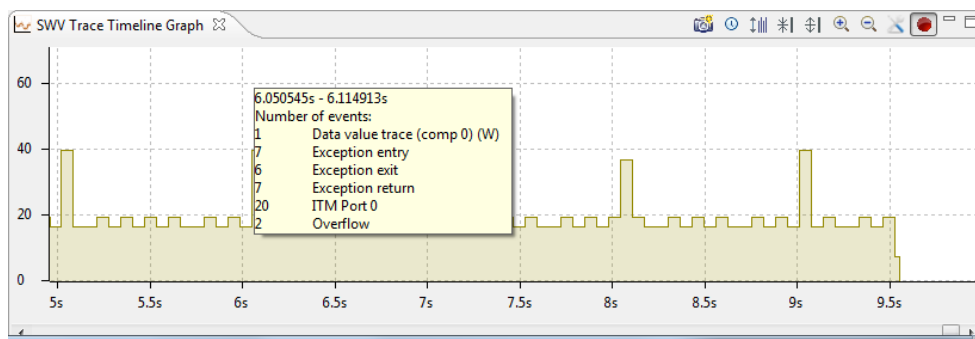
The Serial Wire Viewer master view is the **SWV Trace Log**, and the accompanying graphical timeline chart. The **SWV Trace Log** lists all trace records that has been recorded during the current debug session.



| Index | Type | Data | Cycles | Time(s) | Extra info |
|-------|------------------|------|-----------|----------------|--------------|
| 2306 | Exception entry | 15 | 112706252 | 7.04414075 s | |
| 2307 | Exception exit | 15 | 112706292 | 7.04414325 s | |
| 2308 | Exception return | 0 | 112706722 | 7.044170125 s | Packet delay |
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| 2310 | Exception exit | 15 | 112866289 | 7.0541430625 s | |
| 2311 | Exception return | 0 | 112866719 | 7.0541699375 s | Packet delay |
| 2312 | Exception entry | 15 | 113026246 | 7.064140375 s | |
| 2313 | ITM Port 0 | 83 | 113027901 | 7.0642438125 s | |
| 2314 | ITM Port 0 | 121 | 113027978 | 7.064248625 s | |
| 2315 | ITM Port 0 | 115 | 113028055 | 7.0642534375 s | |

Overflow packets: 21

The **SWV Trace Log** provides detailed information on the recorded trace records. If a quick overview of the tracing results is desired, the graphical **SWV Trace Timeline Graph** view is better, as it visualize the trace data over time in an easy to understand manner.



Both the **SWV Trace Log** and the **SWV Trace Timeline Graph** views are updated in real time, and the graph even has smooth scrolling with various zoom capabilities. The graph view provides features for switching between time and clock cycle mode, and has a feature that saves a screenshot of the graph to a file.

SWV DATA TRACE AND GRAPHICAL TIMELINE CHART

The **SWV Data Trace Log**, and its accompanying graphical timeline chart, provides information about current values of memory locations and C variables, and all memory accesses that have been recorded during the current debug session.

The **SWV Data Trace Log** display real-time updated values for selected C variables or memory locations, including different 8/16/32-bit integer and floating point data types. By selecting a monitored data object in the **Watch** pane, the memory access list for that data object is listed in the **History** pane with detailed information as well.

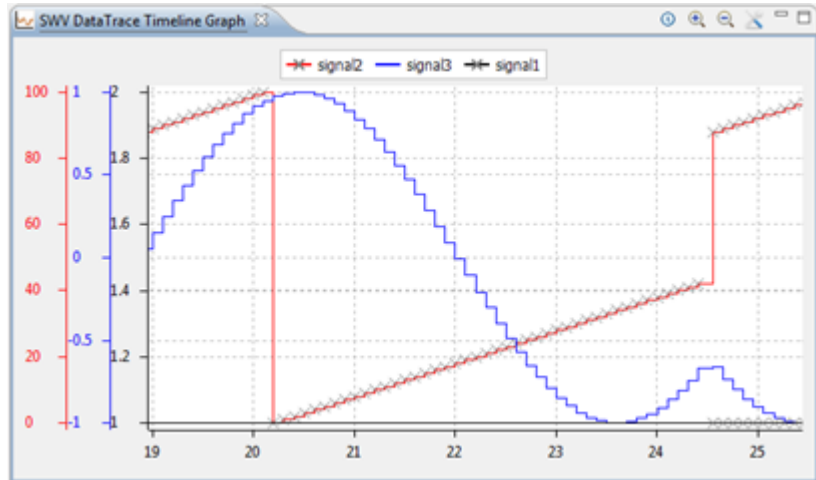
The figure shows the 'SWV Data Trace' window. It has two main panes: 'Watch' and 'History (signal3)'. The 'Watch' pane contains a table with columns 'Comp', 'Name', and 'Value'. The 'History (signal3)' pane contains a table with columns 'Access', 'Value', 'PC', and 'Cycles'. A red box highlights the 'Value' column in the 'Watch' pane with the text 'Variable values are updated in real-time while the application runs at full speed'. Another red box highlights the 'History (signal3)' pane with the text 'Double-click to jump to the editor line that made this memory access'.

| Comp | Name | Value |
|------|---------|------------|
| 0 | signal1 | 1 |
| 1 | signal2 | 39 |
| 2 | signal3 | 0.34995136 |

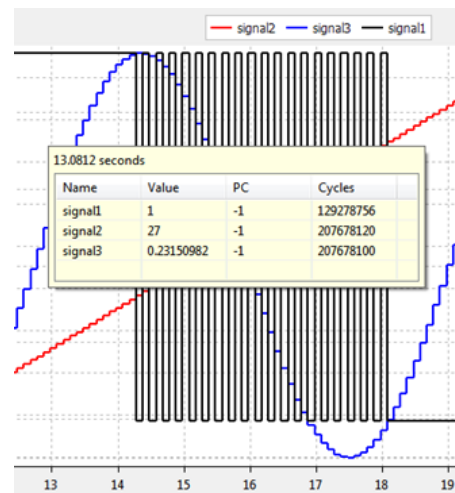
| Access | Value | PC | Cycles |
|--------|------------|--------|------------|
| WRITE | 0.91580963 | 0x1700 | 2895493005 |
| WRITE | 0.871114 | 0x1700 | 2905492998 |
| WRITE | 0.81776625 | 0x1700 | 2915492931 |
| WRITE | 0.75622165 | 0x1700 | 2925492888 |
| WRITE | 0.68712115 | 0x1700 | 2935492533 |
| WRITE | 0.61115515 | 0x1700 | 2945492498 |
| WRITE | 0.5290827 | 0x1700 | 2955492471 |
| WRITE | 0.4417238 | 0x1700 | 2965492435 |
| WRITE | 0.34995136 | 0x1700 | 2975492408 |

If the SWV tracing is configured to emit program counter (PC) values for every memory access, a double click in the memory access history list automatically open the source code file and line number that caused that specific memory access.

Like the **SWV Trace Log**, the **SWV Data Trace Log** has an accompanying graphical **SWV DataTrace Timeline Graph** view. This graphical chart provides unprecedented overview of how different variable values change over time during execution, and how they relate to each other.



By moving the mouse over a specific part of the diagram, a tooltip displays additional information, like timestamp and the exact values of all monitored C variables or memory addresses at that time position.



Both the **SWV Data Trace Log** and the **SWV DataTrace Timeline Graph** views are updated in real time during execution, and the graph even has smooth scrolling with various zoom capabilities. The graph view provides features for switching between time and clock cycle mode, and has a feature that saves a screenshot of the graph to a file.

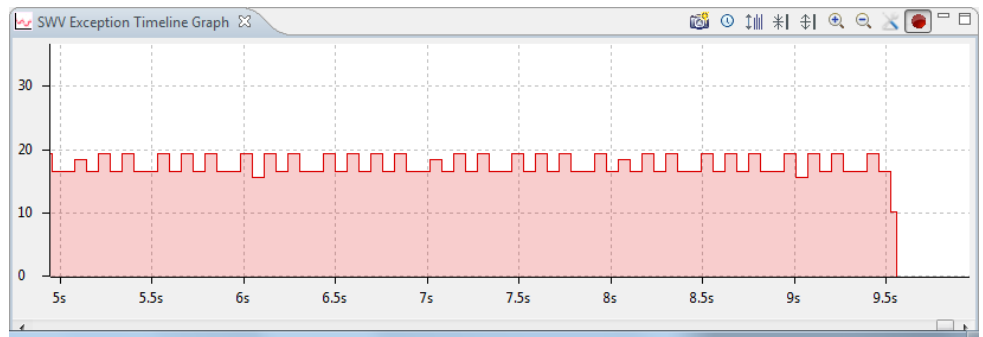
SWV EXCEPTION TRACE LOG AND GRAPHICAL TIMELINE CHART

The **SWV Exception Trace Log** is splitted into two tabs; **Data** and **Statistics**. The **Data** tab and its accompanying graphical timeline chart, provides information about the interrupt and exception events that have been recorded during the current debug session.

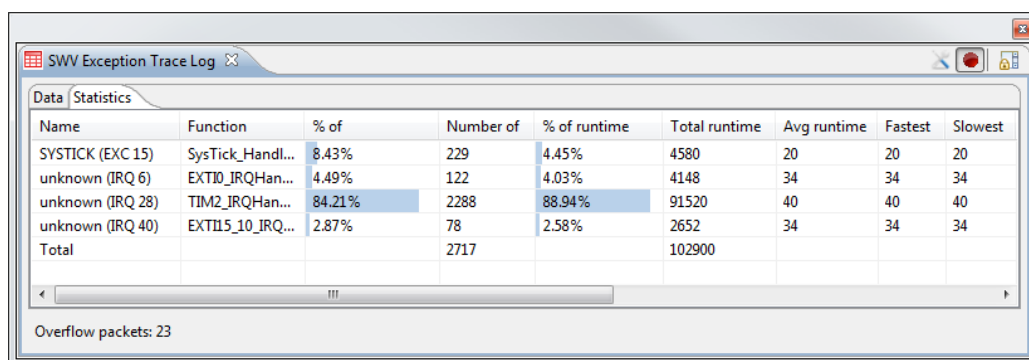
| Index | Type | Name | Function | Cycles | Time(s) |
|-------|------------------|------------------|--------------------|------------|--------------------|
| 7194 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2361287210 | 19.677393416666... |
| 7195 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2361287250 | 19.67739375 s |
| 7196 | Exception return | N/A (EXC 0) | | 2361287809 | 19.677398408333... |
| 7197 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2362487207 | 19.687393391666... |
| 7198 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2362487247 | 19.687393725 s |
| 7199 | Exception return | N/A (EXC 0) | | 2362487806 | 19.687398383333... |
| 7200 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2363687204 | 19.697393366666... |
| 7201 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2363687244 | 19.6973937 s |
| 7202 | Exception return | N/A (EXC 0) | | 2363687803 | 19.697398358333... |
| 7203 | Exception entry | SYSTICK (EXC 15) | SysTick_Handler() | 2364321735 | 19.702681125 s |
| 7204 | Exception exit | SYSTICK (EXC 15) | SysTick_Handler() | 2364321755 | 19.702681291666... |
| 7205 | Exception return | N/A (EXC 0) | | 2364322340 | 19.702686166666... |
| 7206 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2364887198 | 19.707393316666... |
| 7207 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2364887238 | 19.70739365 s |
| 7208 | Exception return | N/A (EXC 0) | | 2364887797 | 19.707398308333... |
| 7209 | Exception entry | unknown (IRQ 6) | EXTI0_IRQHandler() | 2365276242 | 19.71063535 s |
| 7210 | Exception exit | unknown (IRQ 6) | EXTI0_IRQHandler() | 2365276276 | 19.710635633333... |
| 7211 | Exception return | N/A (EXC 0) | | 2365276834 | 19.710640283333... |
| 7212 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2366087192 | 19.717393266666... |
| 7213 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2366087232 | 19.7173936 s |
| 7214 | Exception return | N/A (EXC 0) | | 2366087791 | 19.717398258333... |
| 7215 | Exception entry | unknown (IRQ 28) | TIM2_IRQHandler() | 2367287189 | 19.727393241666... |
| 7216 | Exception exit | unknown (IRQ 28) | TIM2_IRQHandler() | 2367287229 | 19.727393575 s |

Overflow packets: 23

Like the **SWV Trace Log**, the **SWV Exception Trace Log** has an accompanying graphical **SWV Exception Timeline Graph** view.



By moving the mouse over a specific part of the diagram, a tooltip displays additional information dependent on zoom level. If the diagram is zoomed out, summary information is displayed in the tool tip. If the diagram is zoomed in to a certain level, the tooltip display detailed information about the trace record(s) under the mouse.



| Name | Function | % of | Number of | % of runtime | Total runtime | Avg runtime | Fastest | Slowest |
|------------------|------------------|--------|-----------|--------------|---------------|-------------|---------|---------|
| SYSTICK (EXC 15) | SysTick_Handl... | 8.43% | 229 | 4.45% | 4580 | 20 | 20 | 20 |
| unknown (IRQ 6) | EXTI0_IRQHan... | 4.49% | 122 | 4.03% | 4148 | 34 | 34 | 34 |
| unknown (IRQ 28) | TIM2_IRQHan... | 84.21% | 2288 | 88.94% | 91520 | 40 | 40 | 40 |
| unknown (IRQ 40) | EXTI15_10_IRQ... | 2.87% | 78 | 2.58% | 2652 | 34 | 34 | 34 |
| Total | | | 2717 | | 102900 | | | |

Overflow packets: 23

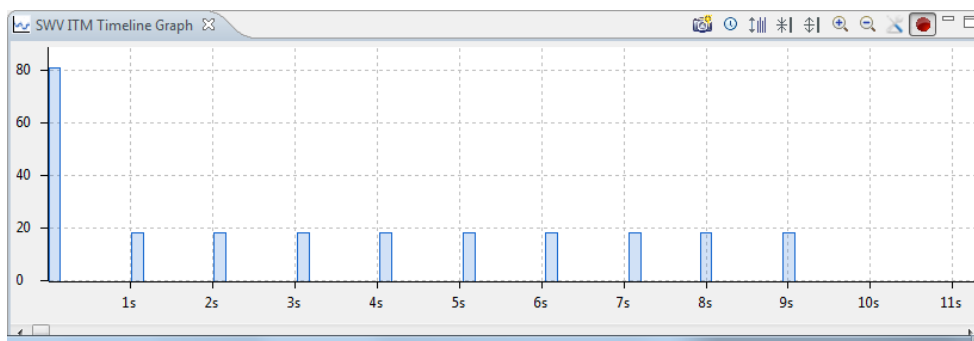
The **Statistics** tab of the **SWV Exception Trace Log** provides detailed statistics about the interrupt events in the target system.

In addition to information about the interrupt use distribution for different interrupt types, valuable timing information is displayed too. Double-clicking on a line in the table automatically opens the editor with the file:line where the corresponding interrupt handler is implemented!

SWV ITM GRAPHICAL TIMELINE CHART

The **SWV ITM Timeline Graph** provides graphical information about the ITM trace output from the target application, such as trace records from redirected printf() output.

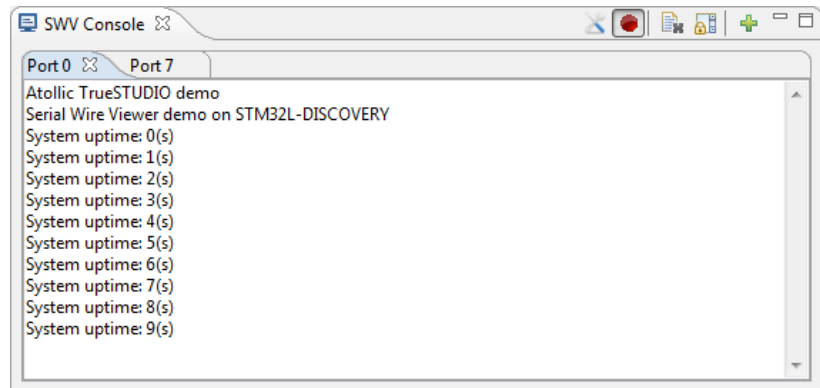
This debugger view can be quite useful. If the application writes a data byte to a certain ITM channel before and after a code section is executed, this gives direct information about when execution of that code section started and stopped. It is also possible to subtract the timestamp of the two ITM packages to obtain a precise measurement of its exact execution time. This is very useful for timing critical sections of code.



By moving the mouse over a specific part of the diagram, a tooltip displays additional information dependent on zoom level. If the diagram is zoomed out, summary information is displayed in the tool tip. If the diagram is zoomed in to a certain level, the tooltip display detailed information about the trace record(s) under the mouse.

THE ITM CONSOLE

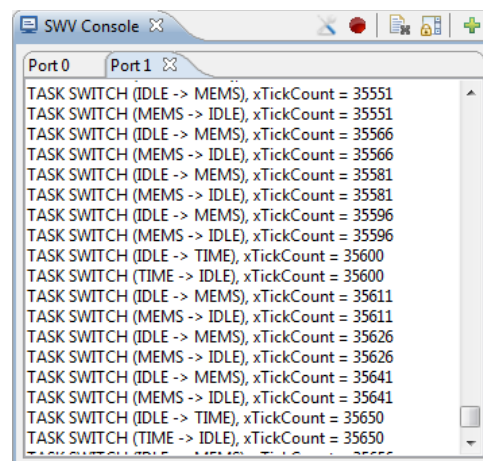
The **ITM Console** is specifically designed to print human readable text output from the target application, typically by the means of a `printf()` that redirects its output to an ITM channel.



The **ITM Console** prints data from the ITM channel 0 by default, but by clicking on the **Add channel** toolbar button, additional tabs with output from other ITM channels can be created. The application can then be instrumented to let different subsystems write trace strings to different channels.

For example, the main application can write trace strings to ITM channel 0, while a Flash file system or TCP/IP stack might be instrumented to write trace messages to the ITM channel 7.

Not only can their output be individually turned on or off in the **SWV Configuration** dialog, but the output end up in unique console windows too. Below is an example where an RTOS kernel is printing information to ITM channel 1.



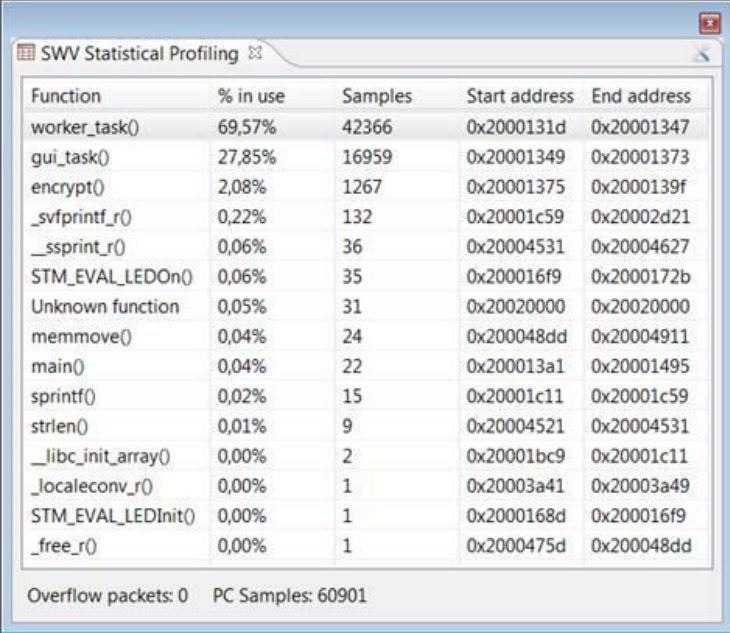
RTOS Kernel information printed on ITM channel 1.

SWV STATISTICAL PROFILING

The **SWV Statistical Profiling** view uses the Serial Wire Viewer program counter (PC) sampling, to provide statistical samples of where the CPU executes code at periodic snapshots. This enables the debugger to work out in which C-functions execution is made most often, thus enabling an execution time profiling feature.

As the program counter values are only received at periodic snapshots, the profiling is built on statistical trends, rather than exact and 100% accurate information. It is for example possible that execution of a function (that may be running frequently) is completely missed if the PC samples by random happens to be taken at snapshot times where the processor is executing other code.

Over time however, this risk becomes smaller and smaller, and so the statistical profiling feature still is very valuable in understanding where in your program execution spend most time.



The screenshot shows a window titled "SWV Statistical Profiling" with a table of function usage statistics. The table has five columns: Function, % in use, Samples, Start address, and End address. The data is as follows:

| Function | % in use | Samples | Start address | End address |
|---------------------|----------|---------|---------------|-------------|
| worker_task() | 69,57% | 42366 | 0x2000131d | 0x20001347 |
| gui_task() | 27,85% | 16959 | 0x20001349 | 0x20001373 |
| encrypt() | 2,08% | 1267 | 0x20001375 | 0x2000139f |
| _svfprintf_r() | 0,22% | 132 | 0x20001c59 | 0x20002d21 |
| __ssprintf_r() | 0,06% | 36 | 0x20004531 | 0x20004627 |
| STM_EVAL_LEDOn() | 0,06% | 35 | 0x200016f9 | 0x2000172b |
| Unknown function | 0,05% | 31 | 0x20020000 | 0x20020000 |
| memmove() | 0,04% | 24 | 0x200048dd | 0x20004911 |
| main() | 0,04% | 22 | 0x200013a1 | 0x20001495 |
| sprintf() | 0,02% | 15 | 0x20001c11 | 0x20001c59 |
| strlen() | 0,01% | 9 | 0x20004521 | 0x20004531 |
| __libc_init_array() | 0,00% | 2 | 0x20001bc9 | 0x20001c11 |
| _localeconv_r() | 0,00% | 1 | 0x20003a41 | 0x20003a49 |
| STM_EVAL_LEDInit() | 0,00% | 1 | 0x2000168d | 0x200016f9 |
| _free_r() | 0,00% | 1 | 0x2000475d | 0x200048dd |

At the bottom of the window, it displays "Overflow packets: 0" and "PC Samples: 60901".

SUMMARY

Many of the hardware components of electronics products are becoming less expensive as time goes on. This trend is actually driving up software development and testing costs, as the adoption of cheaper hardware enables more product features that must be supported by software. This means more bugs to find, and less time to find them. The information provided by SWV and ITM can be valuable tools in a developers repertoire when used properly.

Being able to visualize the time evolution of specific variables and other events as the application executes can provide the developer valuable insights into topics such as:

- Whether or not control algorithms are functioning properly
- Whether or not memory locations are being corrupted inadvertently
- Whether or not pointers are behaving as expected
- Locating sections of code that require optimization
- Locating specific lines of code that are causing memory corruption
- Determining whether or not interrupts are firing as expected

The problems listed above, as well as others, are frequently the source of “million dollar bugs,” so named because of the expense in time, money, and potential loss of company reputation associated with these bugs. There are certainly further debugging strategies that can be implemented based on the information provided by SWV and ITM. These are only limited by the developer’s imagination.

Atollic TrueSTUDIO® provides embedded developers with advanced features for powerful debugging using Serial Wire Viewer technology, while at the same time simplifying their work and shortening development and testing time.

Atollic provides a family of well integrated tools for professional embedded systems development and debugging, static source code analysis, test automation and test quality measurement.

More information about Atollic, **Atollic TrueSTUDIO®**, **Atollic TrueINSPECTOR®**, **Atollic TrueANALYZER®** and **Atollic TrueVERIFIER™** products is available here:

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