



APPLICATION NOTE 3593

## MAXQ Competitive Analysis Study

*Abstract: To demonstrate the abilities of the MAXQ microcontroller, we took benchmark code written for a competitor's microcontroller and ran it on the MAXQ2000. The results show that the MAXQ is one of the best 16-bit microcontroller cores available.*

### Introduction

The MAXQ's unique transfer-triggered architecture makes it a top performer in the 16-bit microcontroller market. The MAXQ instruction set features single-clock and instruction-cycle operations for jumps, calls, returns, loop control, and arithmetic operations. As a result the MAXQ enables applications to process more data in less time than other microcontrollers. Designers can thus add more functionality in their applications or reduce power consumption by completing required tasks quickly and spending more time in low-power stop modes.

To demonstrate the MAXQ's capabilities for this competitive analysis, we took benchmark code written to showcase the MSP430, ran it on the MAXQ, and monitored MAXQ performance. The competitor's code initially made the MAXQ function comparatively slow and inefficiently. Later when Rowley's highly optimized CrossWorks compiler for the MAXQ was released to the market, we reran the benchmark code. We found that Rowley's compiler used MAXQ architectural features more effectively, and that the MAXQ outperformed both the Texas Instruments (TI) MSP430 and the Atmel AVR. The MAXQ executed the same code in fewer clock cycles. In addition, this accelerated performance did not penalize the user with extra code size—the MAXQ's code size is within 2% of the competitors' code sizes.

This application note presents the details of our study of the MAXQ, Atmel AVR, and TI MSP430 architectures. This study is transparent—there are no tricks of compiler optimizations or specialized code made to force one microcontroller to perform better than another. Project files and source code are provided on the [Maxim Web](#) site so that the results can be duplicated. The results of this study (and other MAXQ performance studies) can be found at [MAXQBenchmark](#).

### Notes About Methodology

Of the two compilers in this study, the IAR Embedded Workbench and the Rowley CrossWorks, we used Rowley's compiler to generate the MAXQ's benchmark data because it made the best use of MAXQ capabilities. Both the IAR and Rowley compiler results were used for the MSP430 and the AVR microcontroller tests.

The data for execution time were gathered with the simulators that ship with IAR's Embedded Workbench and Rowley's CrossWorks toolsets. The execution cycles counted did not include startup time; the count started at the entry point into the **main()** function and ended with the **main()** function's return statement.

Code sizes are in bytes and include both CONSTANT and CODE segments. This is because some tools include application constants in the CODE segment, which would make a device's code density appear incorrectly high. Combining the sizes of the CODE and CONSTANT segments ensures an equivalent comparison.

In general, we configured the compilers to use their highest code-optimization levels for ALL devices. This typically meant that all optimizations were enabled when targeting the smallest code size, and almost all optimizations were enabled when targeting the fastest code (because some compiler optimizations sacrifice speed for code size). In some instances, the high optimization settings caused problems—the code generated failed to simulate properly, never reaching the return statement. Often, the code began to work when the optimization level changed. We will indicate when such reductions of the optimization level were required. The project files that accompany this application note contain the optimization settings used to generate the benchmark data.

### TI Benchmark

This benchmark is a suite of tests published by Texas Instruments to showcase the MSP430. The suite contains 10 individual benchmarks:

1. 8-bit math routines
2. 8-bit matrix (array) accesses
3. 8-bit switch statements
4. 16-bit math routines
5. 16-bit matrix (array) accesses
6. 16-bit switch statement
7. 32-bit math routines
8. Floating point math routines
9. Finite impulse response algorithm
10. Matrix multiplication

Following the TI test parameters, the MAXQ performed poorly. It generated code that was larger and slower than most of the other microcontrollers. Naturally, the TI study showed the MSP430 the winner in the comparisons. However, there were flaws in TI's methodology that demanded further analysis. Consequently, we examined how the MAXQ performed with the Rowley CrossWorks compiler.

The TI application note, including the source code, is available for [download](#).

## TI Results

The TI study provided results for execution speed (in clock cycles) and code density (in bytes), as shown in **Table 1** and **Table 2**. Note that some of the device names (taken directly from the TI application note) are unclear. For instance, does 8051 refer to a 12-clock, 6-clock, 4-clock, or even 1-clock 8051 architecture?

**Table 1. TI Study Results: Execution Speed (no. of cycles)**

Application	MSP430F135	ATmega8	PIC18F242	8051	H8/300L	MC68HC11	MAXQ20	ARM7-TDMI (Thumb)
8-bit math	299	157	318	112	680	387	421	185
8-bit matrix	2899	5300	20045	17744	9098	15412	31691	2227
8-bit switch	50	131	109	84	388	214	58	146
16-bit math	343	319	625	426	802	508	815	259
16-bit matrix	5784	24426	27021	29468	15280	23164	60214	2998
16-bit switch	49	144	163	120	398	230	51	146
32-bit math	792	782	1818	2937	1756	1446	1034	115
Floating point	1207	1601	1599	2487	2458	4664	1943	108
FIR filter	152193	164793	248655	206806	245588	567139	464558	43191
Matrix multiply	6633	16027	36190	9454	26750	26874	66534	2918
<b>TOTALS</b>	<b>170249</b>	<b>213680</b>	<b>336543</b>	<b>269638</b>	<b>303198</b>	<b>640038</b>	<b>627319</b>	<b>52293</b>

**Table 2. TI Study Results: Code Size (no. of bytes)**

Application	MSP430F135	ATmega8	PIC18F242	8051	H8/300L	MC68HC11	MAXQ20	ARM7-TDMI (Thumb)
8-bit math	172	116	386	141	354	285	352	660
8-bit matrix	118	364	676	615	356	380	378	408
8-bit switch	180	342	404	209	362	387	202	504
16-bit math	172	174	598	361	564	315	286	676
16-bit matrix	156	570	846	825	450	490	526	428
16-bit switch	178	388	572	326	404	405	188	504
32-bit math	250	316	960	723	876	962	338	620
Floating point	662	1042	1778	1420	1450	1429	1596	1556
FIR filter	668	1292	2146	1915	1588	1470	1828	1420
Matrix multiply	252	510	936	345	462	499	494	432
<b>TOTALS</b>	<b>2808</b>	<b>5114</b>	<b>9302</b>	<b>6880</b>	<b>6866</b>	<b>6622</b>	<b>6188</b>	<b>7208</b>

From this data, the MSP430 produced the densest code—45% smaller than the Atmel AVR microcontroller. The MSP430 also appeared to perform best, with the exception of the 32-bit ARM processor. These results also showed the MAXQ to be comparatively slow and inefficient.

## Flaws with the TI Benchmark Study

The manner in which TI produced its benchmarks raised some questions.

The first problem is that TI did not use any optimizations in their study. TI argued against compiler optimizations in order to remove the compiler from consideration and to make the microcontroller perform on its own. The problem with this argument is that engineers still use a compiler to generate machine code. If a compiler does not take advantage of the architectural features of a microcontroller when optimizations are not enabled, then you do not get a realistic idea of the microcontroller's performance. In addition, benchmarks are only valuable if they model real applications. An engineer is likely to enable optimizations for size or speed in a real application, and these should thus be included as part of the benchmark study.

The second flaw in the TI benchmark study is that they only considered one compiler. Admittedly, the Rowley compiler was not available to TI at that time. Now available, the Rowley compiler dramatically updates the earlier TI results.

## Maxim's Approach

As explained above, our reevaluation of the TI benchmark focused on the MSP430, Atmel AVR, and MAXQ architectures. We considered execution and code size data for both the IAR Embedded Workbench and the Rowley CrossWorks toolsets. All results for execution speed were obtained through simulation.

The MAXQ device in this study was the MAXQ2000 microcontroller. In addition to an array of peripherals including an LCD controller, the MAXQ2000 has 16 16-bit accumulators and a 16 x 16 hardware multiply accelerator. For this study, we enabled the hardware multipliers on all three devices under test—we assumed that if performance on mathematical computations (such as a FIR filter) was important, a designer would choose a microcontroller with a multiply accelerator.

For the MSP430 device, we targeted the MSP430F149, a different device than TI targeted in their study (the MSP430F135). We chose the F149 because it has a hardware multiply unit, making comparison to the MAXQ2000 more equitable.

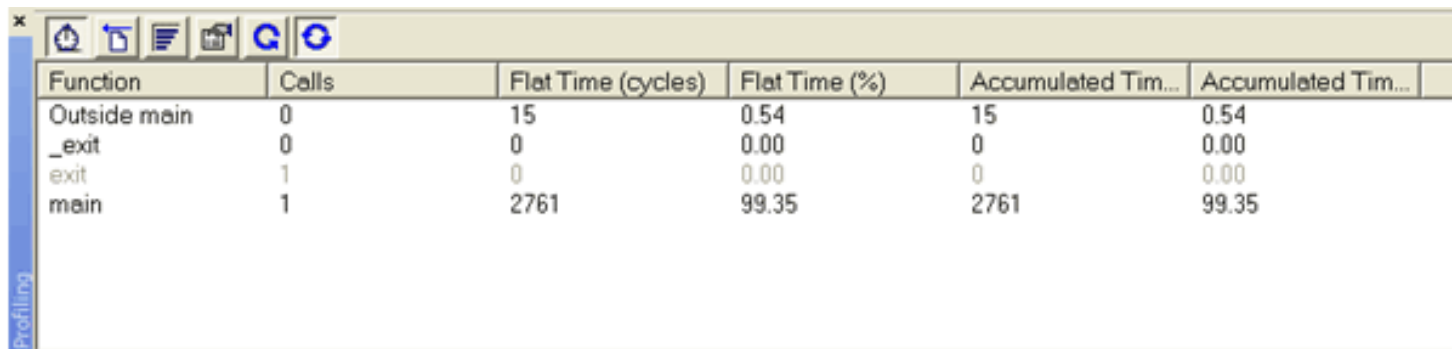
The ATmega8 was selected for study because the current IAR compiler could generate code using the hardware multiplier for this microcontroller. The IAR compiler could not do so for the other AVR devices like the ATmega64 or ATmega128.

Gathering benchmark results from both toolsets was straightforward. In IAR, the code size data is found in a map file (make sure it is generated under *Project Options* → *Linker* → *List*). Scroll down to the bottom of the map file and the following three lines appear:

**184 bytes of CODE memory**  
**80 bytes of DATA memory**  
**66 bytes of CONST memory**

As mentioned earlier, we count both CODE and CONST memory sections in the total code size, because compilers differ on where they place constant program data. For testing, the only legitimate way to compare code size is to include the constant size.

To find execution cycles in IAR, select the Simulator as the Debug tool and begin debugging. Launch the code profiler under *View* → *Profiling*. Click the *Activate* button and the *Autorefresh* button (see **Figure 1**). The debugger should automatically run to the first line of the C code. Press the *Run* key, and (if no breakpoints are set) the IAR debugger terminates at program exit. Look at the code profiler and report the number of cycles under *Accumulated Time* for **main()**—this is the number of cycles spent in the **main** routine and all subroutines called by **main**.



Function	Calls	Flat Time (cycles)	Flat Time (%)	Accumulated Tim...	Accumulated Tim...
Outside main	0	15	0.54	15	0.54
_exit	0	0	0.00	0	0.00
exit	1	0	0.00	0	0.00
main	1	2761	99.35	2761	99.35

Figure 1. IAR Code Profiler: accumulated time (cycles) means the number of cycles spent in that routine and all subroutines which it calls.

Finding the generated code size in the Rowley toolset is also very easy. When the project builds, the Project Explorer lists the code size with the project. **Figure 2** shows that for the MSP430F149, the 16-bit math benchmark code size is 238 bytes.

Project Items	Code	Data
Solution 'msp430f135_benchmarks' (10 projects)		
16bit math	238	
16bit matrix	312	
16bit switch	230	
32bit math	384	
8bit math	262	
8bit matrix	232	
8bit switch	230	
FIR filter	952	
floatingpoint	982	
Matrix multiplication	290	

Figure 2. Rowley Project Explorer shows code size details for each project.

Determining the number of execution cycles in the Rowley tool is not quite as easy as with IAR—Rowley does not automatically stop at the end of the program nor does it separate where the cycles are spent. You must reset the cycle counter upon entry to the main program. To do this, first start debugging the program. When the compiler stops at the entry point to main, reset the cycle counter by double clicking on it.

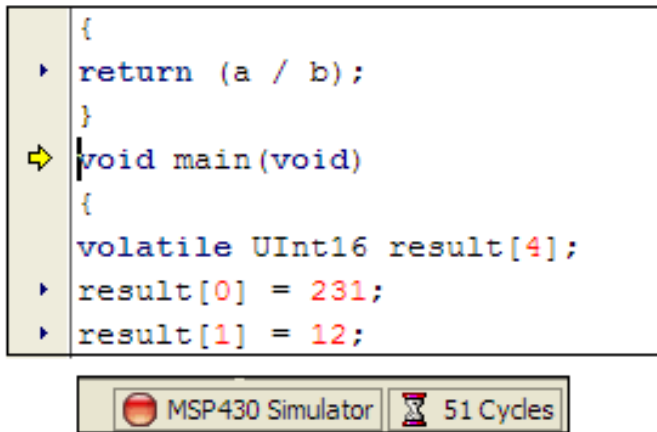


Figure 3. When the Rowley simulator stops at main(), reset the cycle counter (the picture with the hourglass) by double-clicking on it.

Next, set a breakpoint at the end of the application. (Note that lines with the blue triangles in the margins indicate where you can set breakpoints.) Run to the breakpoint and record the number of cycles reported.

There are other possible complications with using the Rowley simulator.

1. Depending on the optimizations, you may only be able to simulate at the assembly level, in which case it is more difficult to find the end of the application. The best approach is to scan through the code and find the next **RETURN** statement in the assembly code, set your breakpoint there, and run to it.
2. The simulator may not always stop at the main entry point. When this occurs, try pressing the Restart Debugging button. You may also need to manually find the main entry point and set a breakpoint there.

## Compiler Settings

When using the IAR toolset, the compiler options window in the project options is configured for the highest optimization level with all optimizations enabled (see **Figure 4**). To change between targeting smallest code and fastest execution, switch

the selected radio button from *Size* to *Speed*.

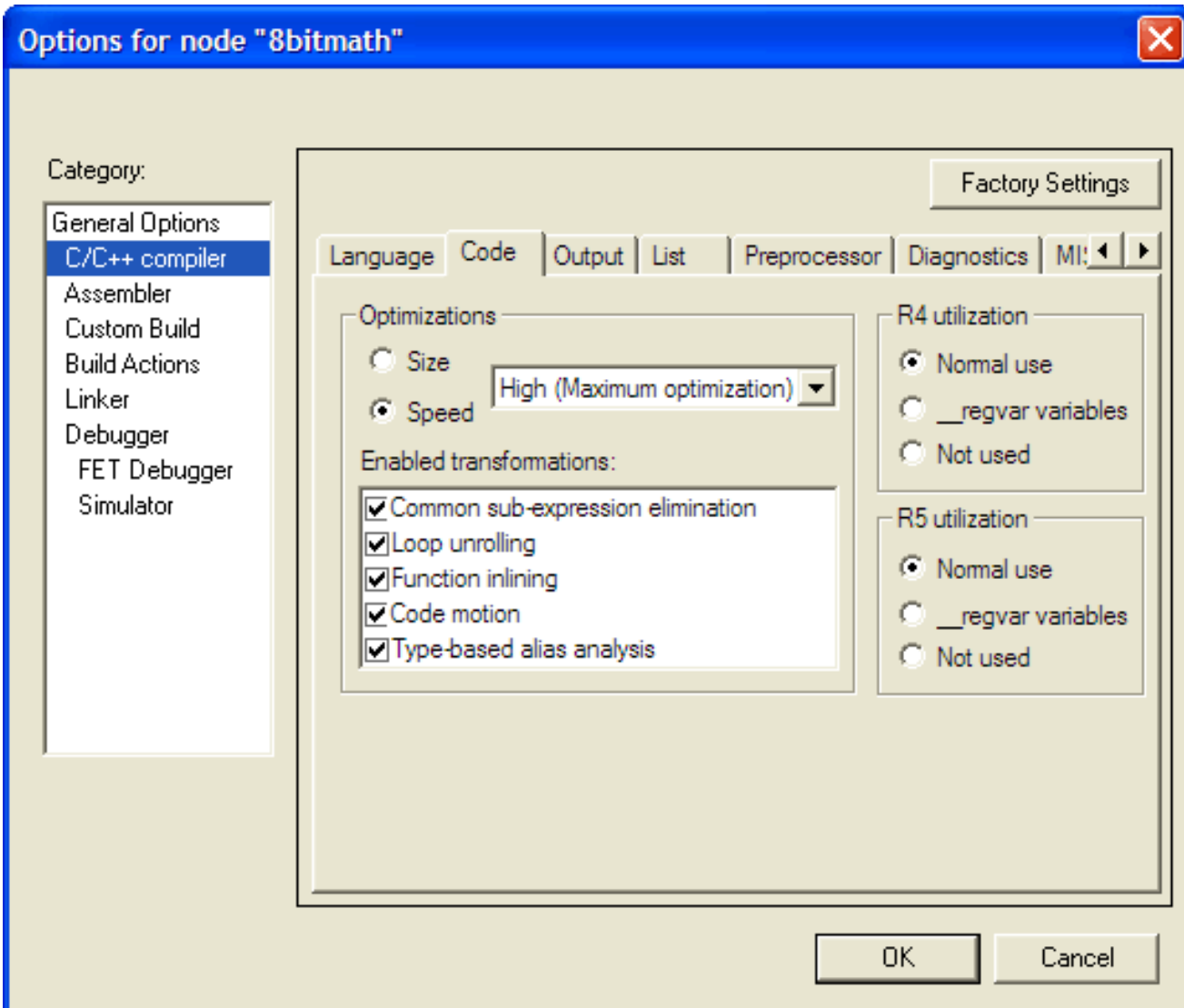


Figure 4. Options for the IAR compiler: all optimizations are enabled. The radio button switches the compiler between optimizing for speed and for size.

Rowley's CrossWorks allows users to create build configurations in addition to the default Debug and Release configurations. Therefore, the benchmark projects for this study also included the *Fastest* (see **Figure 5**) and *Smallest* (**Figure 6**) configuration options. The *Fastest* configuration removes any optimization that values code size at the expense of an instruction cycle.

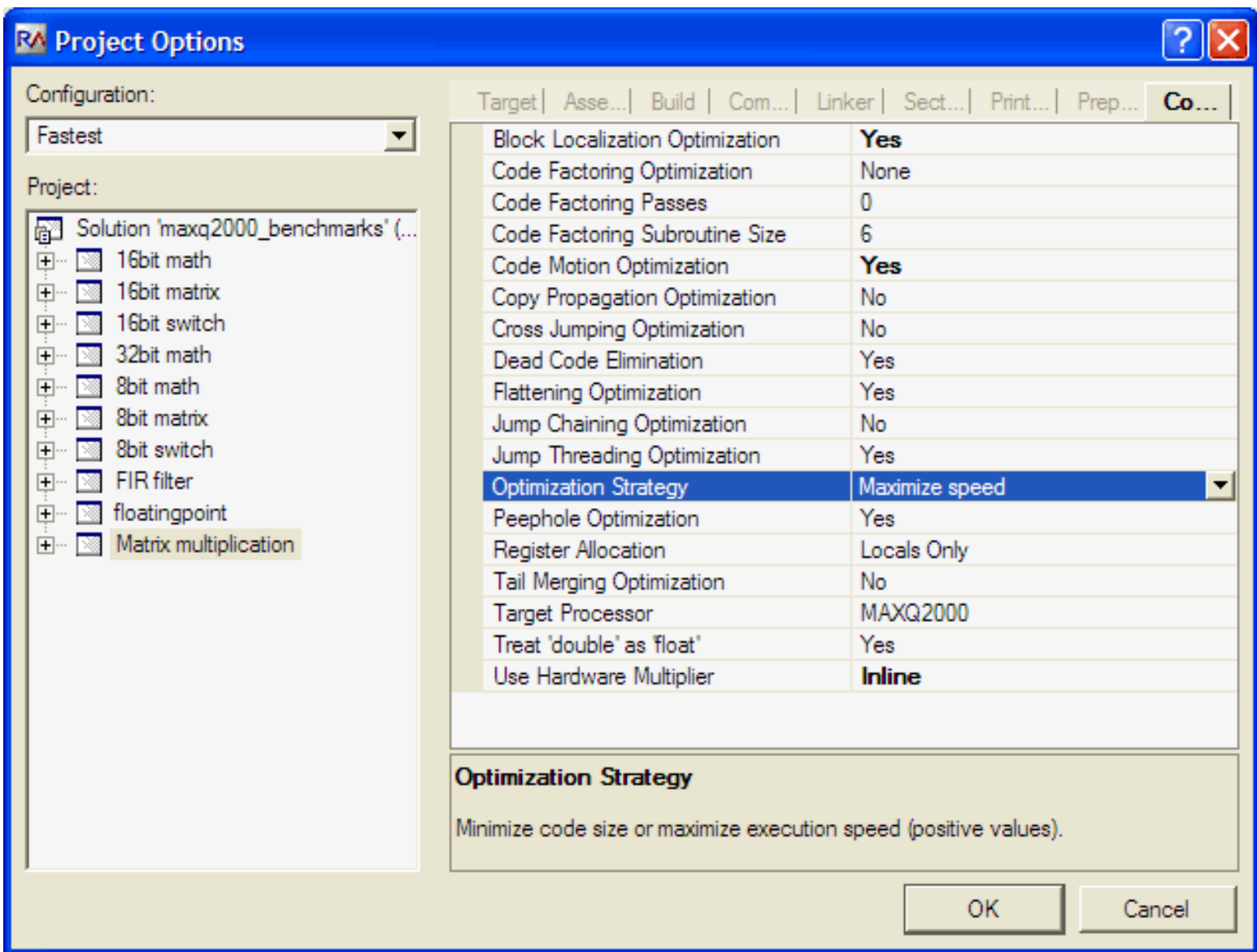


Figure 5. Project options used in Rowley's CrossWorks for the fastest configuration.

The settings for the smallest configuration appear in Figure 6. Options that favored code size at the expense of cycles were enabled, and the overall optimization strategy was to *minimize size*.

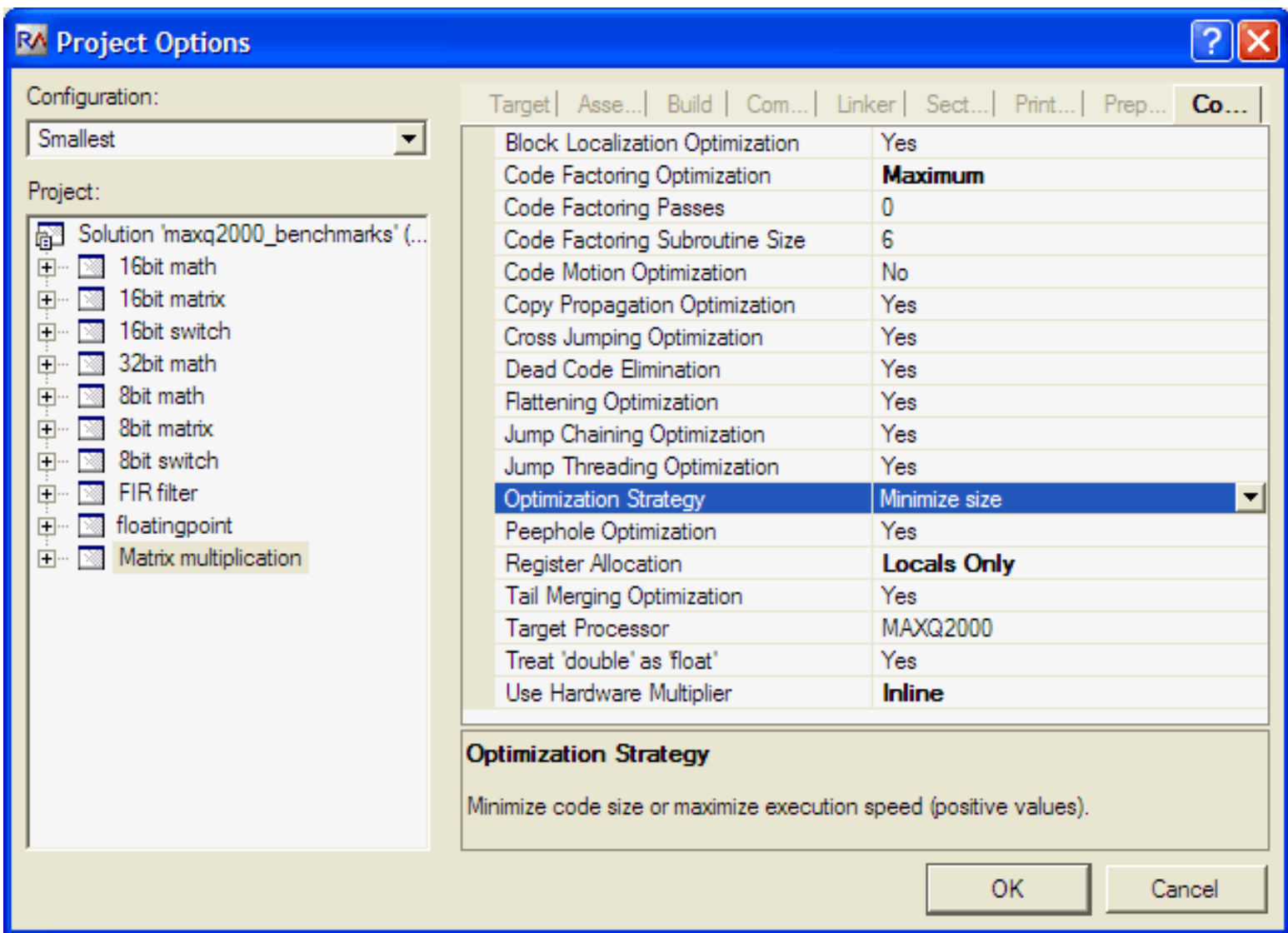


Figure 6. Project options used in Rowley's CrossWorks for the Smallest configuration.

The project and source files for each benchmark run by Maxim are available at [www.maxim-ic.com/products/microcontrollers/maxq/performance/competitive.cfm#compiler\\_detail\\_links](http://www.maxim-ic.com/products/microcontrollers/maxq/performance/competitive.cfm#compiler_detail_links). The configurations in these project files are the same configurations used for the benchmarking. Links to trial versions of the IAR and Rowley tools are available with other [third-party tools](#) on the Maxim website, so you can easily reproduce these benchmark results.

# MAXQ Benchmark Results

Tables 3 and 4 show the MAXQ benchmark results. Execution speed is again given as clock cycles and code size is given in bytes.

**Table 3. Results from Maxim's Study: Execution Speed (no. of cycles)**

Application	MSP430F149 IAR		MSP430F149 Rowley		ATmega8 IAR		ATmega8 Rowley		MAXQ2000 Rowley	
	Small	Fast	Small	Fast	Small	Fast	Small	Fast	Small	Fast
8-bit math	243	243	276	272	110	110	279	278	278	245
8-bit matrix	1629	963	6243	2659	1508	1074	7348	3763	3461	2947
8-bit switch	31	31	24	24	84	36	45	45	39	39
16-bit math	219	219	250	250	275	266	348	330	194	191
16-bit matrix	1906	899	6755	3171	1147	697	5251	5250	3205	2691
16-bit switch	30	30	24	24	111	44	50	50	39	39
32-bit math	575	575	790	716	746	731	995	885	545	521
Floating point	784	784	1097	921	1614	1565	1491	919	763	744
FIR filter	86042	82748	90812	82592	82779	82779	73598	66249	62280	59470
Matrix multiply	4254	2761	6036	5436	7799	2396	11081	9231	3704	3027
<b>TOTALS</b>	<b>95713</b>	<b>89253</b>	<b>112307</b>	<b>96065</b>	<b>96173</b>	<b>89698</b>	<b>100486</b>	<b>87000</b>	<b>74508</b>	<b>69914</b>

Figure 7 graphs the data for execution speed. Only the fastest results are shown. Speed is measured in execution cycles—a smaller bar means better performance.

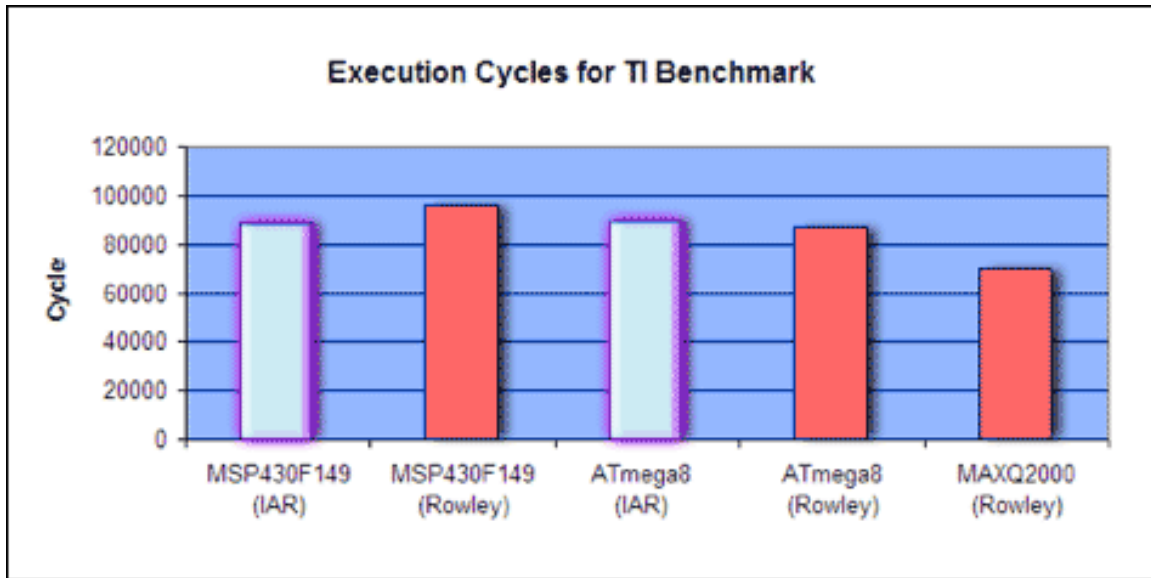


Figure 7. Execution speed results for the fastest configuration setting. The smaller MAXQ2000 bar shows better performance.

**Table 4. Results from Maxim's Study: Code Size (no. of bytes)**

Application	MSP430F149 IAR		MSP430F149 Rowley		ATmega8 IAR		ATmega8 Rowley		MAXQ2000 Rowley	
Configuration	Small	Fast	Small	Fast	Small	Fast	Small	Fast	Small	Fast
8-bit math	192	192	258	262	98	98	212	212	248	284
8-bit matrix	152	180	240	232	318	304	220	250	202	222
8-bit switch	180	180	230	230	312	164	202	200	152	152
16-bit math	140	140	220	220	162	154	222	238	162	164
16-bit matrix	240	240	312	312	398	374	294	350	260	378
16-bit switch	178	178	230	230	346	178	212	240	152	152
32-bit math	236	236	284	388	306	296	380	460	274	324
Floating point	1100	1100	966	1004	1026	1046	816	936	1018	1090
FIR filter	1178	1174	924	966	1258	1258	860	896	1024	1044
Matrix multiply	266	250	312	316	476	324	294	348	254	264
<b>TOTALS</b>	<b>3862</b>	<b>3870</b>	<b>4076</b>	<b>4160</b>	<b>4700</b>	<b>4196</b>	<b>3712</b>	<b>4130</b>	<b>3746</b>	<b>4074</b>

The following graph (**Figure 8**) shows the code size data for the smallest configuration results. Code size is measured in number of bytes—a smaller bar means better code density.

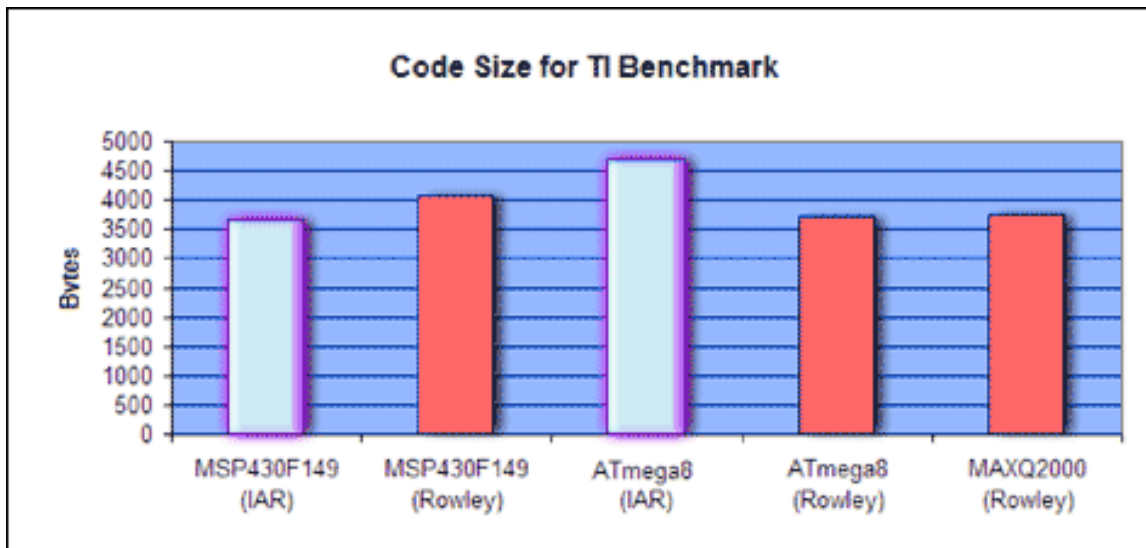


Figure 8. Code size results for the smallest configuration setting. The MAXQ2000's smaller bar indicates better code density.

**Table 5. The Compiler Versions for This Study**

Microcontroller	Compiler	Version
MAXQ2000	Rowley	CrossWorks for MAXQ, Release 1.0, Build 2
MSP430F149	Rowley	CrossWorks for MSP430, Release 1.3, Build 3
MSP430F149	IAR	IAR C/C++ Compiler for MSP430, V3.30A/W32 (3.30.1.1)
ATmega8	Rowley	CrossWorks for AVR, Release 1.1, Build 1
ATmega8	IAR	IAR C/C++ Compiler for AVR, 4.10B/W32 (4.10.2.3)

**Table 6. Issues Encountered When Running These Benchmarks**

Device	Tool	Configuration	Benchmark	Issue
ATmega8	Rowley	Smallest	16-bit matrix	The simulation would not terminate unless the Code Factoring optimization was set to NONE.
ATmega8	IAR	Fastest	8-bit matrix, 16-bit matrix	The simulation would not terminate unless the optimization level was set to medium instead of high.
ATmega8	IAR	Smallest	FIR filter	Simulation would not terminate even at lowest optimization level. The numbers included in Table 3 and Table 4 are for the FIR filter in the fastest configuration.
ATmega8	IAR	Both	Matrix multiplication	The simulation would not terminate on the ATmega8, ATmega16, or ATmega32 targets. The project was targeted instead for the ATmega64.

## Analysis and Summary

Across different compilers and with optimizations enabled, the above results show that the MSP430 is not the best performing microcontroller, even when running TI's specially crafted benchmark code.

When considering the total number of execution cycles required to run the entire benchmark suite, the MAXQ2000 outperforms the MSP430F149 and the ATmega8. The MAXQ2000 runs in 69,914 cycles, while the MSP430F149 (IAR) and ATmega8 (Rowley) take 89,253 and 87,000 cycles, respectively. When considering the total size for the benchmark code, the best-case results for the three microcontrollers vary by only 2%, making any difference in code size irrelevant.

Since code density is not a factor for this benchmark, we look deeper into the execution speed results. The total execution-cycle results are heavily weighted by the FIR filter results, where the MAXQ2000 clearly outperforms the competition. The MAXQ2000 is the best performer on the math benchmarks except for the ATmega8 in the 8-bit math benchmark. The MAXQ2000's weakest performance is on the 8-bit and 16-bit matrix benchmarks, which copy items from one multidimensional array to another.

To this point, we are only considering the performance of the test microcontrollers in terms of clock cycles. We have not considered the speed at which a device can run. For the sake of absolute comparison, we use benchmark iterations per second—the number of times that the entire TI benchmark suite can run in a second. **Table 7** shows that when all devices run at the same clock speed, the MAXQ2000 is 28% faster than the MSP430F149 and 24% faster than the ATmega8. When the devices run at the maximum clock rate, the MAXQ2000 is 56% faster than the ATmega8 and 218% faster than the MSP430F149.

**Table 7. Results from Maxim's Study: Speed (Iterations per Second and at FMAX)**

Device	Cycles	F <sub>max</sub>	Iterations/s at 1MHz	Iterations/s at F <sub>max</sub>
MSP430F149	89,253	8	11.20	89.60
ATmega8	87,000	16	11.49	183.84
MAXQ2000	69,914	20	14.30	286.00

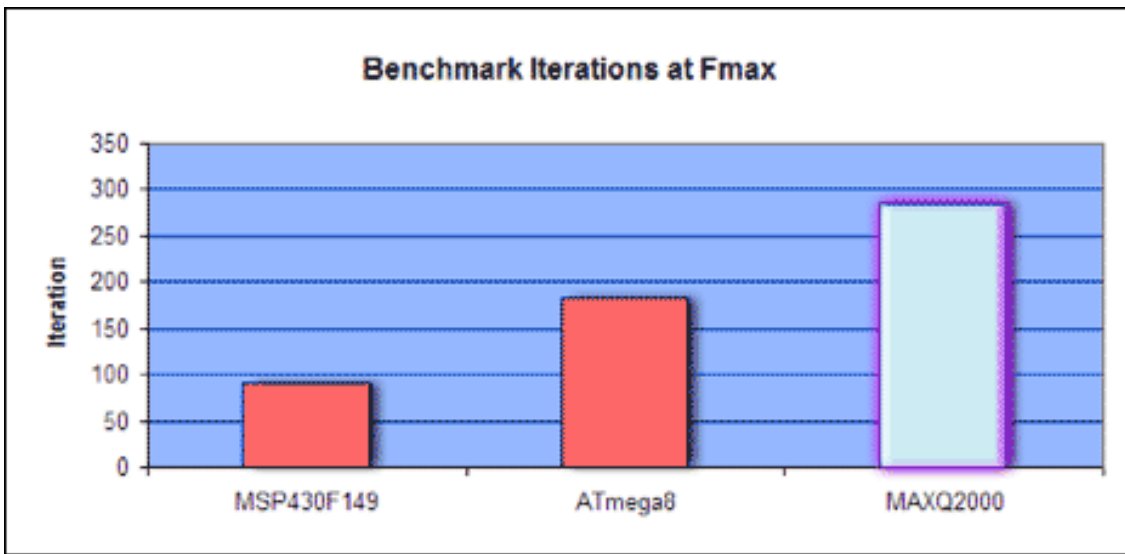


Figure 9. Benchmark iterations per second when running at the maximum clock rate. The taller MAXQ2000 bar shows better performance.

How should we summarize the results of the Maxim benchmark study? At the very least, it counters the results of the TI benchmark study, which showed the MAXQ microcontroller architecture as unremarkable. This updated study shows that the MAXQ2000 is a code-efficient, fast microcontroller that should be considered for any new designs and redesigns that will benefit from a higher performance microcontroller.

This study is part of an ongoing effort. Please visit the homepage for [MAXQ benchmarking](#) for additional and updated studies. An evaluation kit is available for the MAXQ2000 microcontroller. For information on the EV kit, links to demonstration code, software, and application information, go to [Evaluate the MAXQ2000 Microcontroller with the MAXQ2000-KIT](#).

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Application Note 3593: [www.maxim-ic.com/an3593](http://www.maxim-ic.com/an3593)

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