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# PHILIPS CHALLENGES 8-BIT MCUS

## *New 32-Bit ARM7 Microcontrollers With Flash Memory Start at $1.47*

***By Tom R. Halfhill {10/10/05-01}***

If you have $1.50 in pocket change, you can buy two quarts of gasoline, a Big Mac with cheese at McDonald's, or a 32-bit microcontroller with a 70MHz ARM7 processor and 8KB of internal flash memory. The choice is clear.

In the latest attempt to lure embedded-systems designers away from 8- and 16-bit MCUs, Philips Semiconductor has introduced three new 32-bit MCUs with the ubiquitous ARM7TDMI processor core. The lowest-priced part—the LPC2101—has 8KB of on-chip flash memory and starts at only $1.47 in large volumes. That appears to be a new low price for flash-integrated ARM7 MCUs in this relatively high performance class (70MHz, 63 Dhrystone mips). The other two parts—the LPC2102 and LPC2103—have 16KB or 32KB of on-chip flash and cost $1.85 or $2.20, respectively.

All three parts are stuffed with peripherals, timers, and other accoutrements of general-purpose MCUs. In addition, Philips has included features to address the shortcomings of previous 32-bit MCUs and to duplicate some advantages of 8- and 16-bit devices. In particular, Philips has added new power-saving modes and has accelerated the general-purpose I/O (GPIO) interface so it can perform the bit-banging tricks so dear to 8-bit programmers.

Samples of the LPC2101, LPC2102, and LPC2103 will be available in November, and production quantities are scheduled to be available in December. Volume pricing is based on 10,000-unit quantities. The new devices extend the popular LPC2000 family, which now includes about two dozen ARM7 MCUs. (See *MPR 5/19/03-01*, "Philips Shows Flashy MCUs.")

### Fab Improvement Boosts Performance

At 70MHz, the new chips are 10MHz faster than any previous ARM7-based MCUs from Philips and are among the fastest ARM7 MCUs on the market. (Atmel has some ARM7 MCUs running at 82MHz.) To squeeze out a little more performance, Philips has improved the 0.18-micron fabrication process with which the company manufactured previous devices in the LPC2000 family. Now described as a 0.16-micron process, the new fab lines are running in the Netherlands and Singapore—the latter as a joint venture with TSMC. The proprietary Philips embedded-flash process can integrate zero-wait-state flash memory on the same die as the processor core.

In the LPC2000 family, Philips provides a much wider flash-memory interface than is found in other ARM7 MCUs, particularly those that package flash as a separate die in a multichip module. The Philips MCUs have a 128-bit-wide interface between the ARM7 processor core and internal flash, whereas most other MCUs with flash have 16- or 32-bit interfaces. The wider interface allows the processor to fetch four 32-bit words at a time.

Even so, flash memory is much slower than on-chip SRAM, so Philips provides four 128-bit prefetch buffers. One is a prefetch buffer for ARM instructions, and another buffers their data. (The ARM7TDMI-S cores in these MCUs have no instruction or data caches.) A third buffer speculatively prefetches instructions. The fourth buffer is a repository for any series of instructions containing a branch. The main purpose of these buffers is to prevent a branch or data access from stalling the processor, especially during real-time operations. In some cases, the processor can execute tight loops by

fetching instructions directly from a buffer instead of from flash memory.

Of course, the Philips MCUs also have fast internal SRAM for storing time-critical code and data. The LPC2101 has 2KB, the LPC2102 has 4KB, and the LPC2103 has 8KB. The amounts of SRAM and flash memory are the only features distinguishing these devices from each other. Their integrated peripherals and I/O interfaces are identical.

MCU vendors disagree on the best way to provide deterministic real-time performance. Atmel and Oki Semiconductor argue that prefetch buffers aren't much more deterministic than CPU caches, because their behavior can vary with different instruction streams. Both companies prefer to rely on faster SRAM and faster flash memory without prefetch buffers. Philips says its wider flash-memory interface and extensive buffers overcome the nondeterministic behavior of caches without the volatility and die-size penalty of SRAM.

If there's any doubt about real-time performance, software developers should run thorough tests on any flash-based ARM7 MCU. There's always the option of storing time-critical code in SRAM, although Philips MCUs tend to have less internal SRAM than other ARM7 MCUs. Some ARM7 MCUs from Philips have up to 64KB of SRAM, but competitors offer as much as 256KB.

### Faster I/O for Bit Bangers

Eight-bit programmers are the skilled hand-tool craftspeople of the software-development trade. They still worry about conserving a few bytes of memory here and there, and they often fashion entire applications using less RAM than a PC programmer would squander on a multimedia splash screen. Sometimes they even resort to ancient techniques like bit banging—emulating a communications protocol in software by directly manipulating the processor's I/O pins. To make 8-bit programmers feel more comfortable in a 32-bit environment, Philips has addressed some shortcomings of other 32-bit MCUs.

Responding to criticism of poor GPIO performance, the new MCUs have a special Fast GPIO controller. As the block diagram in Figure 1 shows, the Fast GPIO controller attaches to the ARM7 local bus instead of to the usual AMBA Advanced Peripheral Bus (APB). As a result, programmers can toggle the GPIO pins at 17.5MHz, four times faster than a conventional GPIO interface. To use the Fast GPIO, software drivers must change, partly because the memory-mapped registers are different. However, to provide backward compatibility with existing drivers and applications, the new MCUs also have a conventional GPIO controller on the APB. Both GPIO controllers share the same I/O buffers and pins. Up to 32 pins are available for this purpose. Either GPIO interface can use all the pins, or they can share them in any combination.

Philips says the Fast GPIO responds quickly enough to handle typical serial-to-serial protocol conversions and some serial-to-parallel conversions, which are especially useful in control systems. Philips also pitches the new LPC210x devices as ideal solutions for systems using a Power Management Bus (PM-Bus). The new PM-Bus standard defines APIs for point-of-load power applications.

Another criticism leveled at 32-bit MCUs—particularly those based on the ARM7—is their lack of atomic read-modify-write instructions. Although the ARM7 has swap instructions (SWP and SWPB) that can exchange a word or a byte between a register and a memory location, it must lock out interrupts to keep another operation from interfering with the sequence. The interrupt lock could disrupt the performance of a hard real-time system. In contrast, common 8-bit MCUs like the 8051 have atomic instructions that perform the whole sequence as a single, uninterruptible operation.

Philips claims to have solved this problem with a new memory-mapped 32-bit register and special port-write hardware. Writing any value to this register with a standard

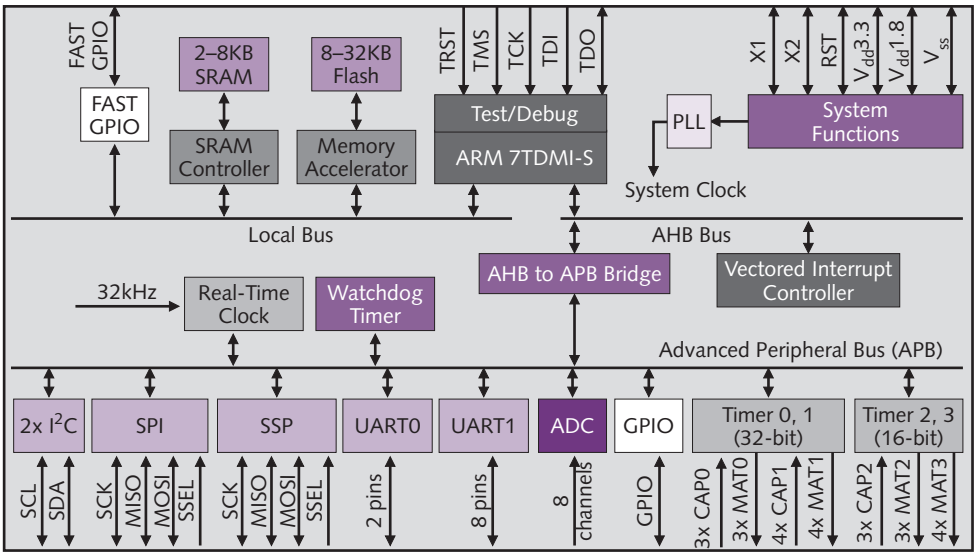


**Figure 1.** LPC210x block diagram. The only differences among the LPC2101, LPC2102, and LPC2103 are their amounts of internal flash memory (8KB, 16KB, or 32KB) and SRAM (2KB, 4KB, or 8KB). The memory accelerator between the flash memory and ARM7 local bus consists of the four 128-bit prefetch buffers described in the text. Note the Fast GPIO controller (upper left), which is also attached to the processor's local bus: it supplements the regular GPIO controller (bottom) on the Advanced Peripheral Bus (APB). Although this conceptual block diagram shows the GPIO controllers on opposite sides of the chip, in practice they share the same 32 GPIO pins.

ARM instruction instantly applies the bit pattern to the Fast GPIO pins on a single clock edge.

MCUs from other vendors can do similar tricks. For example, Atmel introduced a rapid bit-set/clear mechanism in its first ARM-based chips in 1998. Atmel also equips some of its ARM7 MCUs with a peripheral DMA controller, a feature sorely lacking in the ARM7TDMI core.

### New Sleep Modes Save Power

Some disadvantages of 32-bit MCUs are more difficult to overcome. Inevitably, a 32-bit chip consumes more power than an 8-bit chip and costs more money. Tackling the power question, Philips has added better active power management to the new LPC210x devices. They have more power domains (including one for the real-time clock) and power-saving modes. Table 1 shows their various states of slumber.

Trimming the entry-level price of these devices to $1.47 softens another objection to using a 32-bit MCU instead of an 8- or 16-bit chip. Of course, 8-bit MCUs typically cost less than a dollar, and it's probably unrealistic to expect 32-bit chips to completely eliminate the price gap. But 32-bit MCUs are becoming surprisingly inexpensive. Embedded-system designers who would have summarily ruled out a 32-bit device a few years ago should take a fresh look at what's available today.

Yet another objection to 32-bit MCUs—the higher cost of software-development tools—is also under assault. The best third-party tools still cost thousands of dollars more per seat than tools for 8-bit chips. However, some tool vendors are offering entry-level bargains to attract more 32-bit business. Evaluation boards for LPC2000 MCUs start at $99, and some include compilers that allow developers to deploy commercial software at no additional cost, albeit with some restrictions.

For example, Keil Software's $149 LPC2000 evaluation board includes an ARM7 compiler that will generate deployable object code up to 16KB in size. IAR Systems offers a $99 evaluation board with an ARM7 compiler that generates up to 32KB of object code. For programmers accustomed to squeezing their code into 8-bit MCUs, that's enough room for many 32-bit embedded applications. Even if a project can't live within those limits, the low-cost evaluation kits allow developers to determine whether a 32-bit MCU is a viable solution.

### More Competition Coming Soon

As we have noted in previous articles, ARM is aggressively pursuing the huge market for 8- and 16-bit MCUs, which still account for most embedded processors sold each year. (See *MPR 4/4/05-02*, "ARM-Based MCUs Flex Muscles.") The extremely popular ARM7TDMI core is becoming the 8051 of the 32-bit world. It's small (cheap), cacheless (better for deterministic performance), and supports 16-bit Thumb instructions (for greater code density). It's also about 10 years old, so it's well amortized by now, allowing ARM to discount its steep licensing fees in a bid for market share.

ARM licensees are releasing new ARM7 MCUs almost monthly. Table 2 compares the new Philips LPC2101, LPC2102, and LPC2103 chips with similar devices hunting for 8-bit business. A truly comprehensive table wouldn't fit on these pages. More ARM7 MCUs were announced at the ARM developers' conference in early October, after the publication deadline for this article. Indeed, so many ARM7 MCUs are sprouting that vendors are searching for new ways to specialize. In early September, Atmel announced the first two ARM7 MCUs with integrated 10–100Mb/s Ethernet controllers, control-area network (CAN) controllers, full-speed USB 2.0 interfaces, and encryption engines for AES and Triple-DES. The new Atmel devices are intended for embedded-networking systems, unlike the general-purpose MCUs described in Table 2. As the competition heats up, MCU vendors will try even harder to differentiate their products.

For instance, Oki offers the smallest ARM7 MCUs: the new ML67Q4060 and ML67Q4061. At their tiniest, these chips are available in 64-pin wafer-level chip-size (WCSP) packages measuring only 4.84mm × 5.09mm. (See *MPR 4/4/05-02*, "ARM-Based MCUs Flex Muscles.") If board space and 32-bit processing power are critical factors, these devices are hard to beat, although they cost about twice as much as the new Philips MCUs and have less than half the speed.

Two big selling points for Philips are high performance and low prices. We haven't found any ARM7 MCUs with flash memory and other similar features that can match the $1.47 price tag on the new 70MHz LPC2101. Even the most expensive of these three new MCUs is only $2.20. Other vendors will have to adjust their prices to be more competitive.

#### Price & Availability

The Philips LPC2101, LPC2102, and LPC2103 will be sampling in November and are scheduled for volume production in December. Prices in 10,000-unit quantities are $1.47, $1.85, and $2.20, respectively. For more information, see *www.standardics.philips.com/products/lpc2000/*.

| Power Mode | ARM7 Core | Peripherals | SRAM | RT Clock | Wake-Up | Current |
|---|---|---|---|---|---|---|
| **Idle** | Stopped | Active | Active | Active | n/a | <5mA |
| **Power-Down** | Stopped | Stopped | Inactive | Inactive | External int or reset | <10µA |
| **Hibernate** | Power off | Power off | Power on | On | External int or reset | <7µA |
| **Deep Power-Down** | Power off | Power off | Power off | Stopped (osc. off) | External int. or reset | <5µA |

**Table 1.** The new LPC2101, LPC2102, and LPC2103 have all these power-saving modes, which can reduce power consumption to less than 5 microamps. (n/a = not applicable)

| Feature | Philips LPC2101 | Philips LPC2102 | Philips LPC2103 | Atmel AT91SAM7S32 | Oki ML67Q406x | Oki ML67Q500x |
|---|---|---|---|---|---|---|
| CPU Core | ARM7TDMI-S | ARM7TDMI-S | ARM7TDMI-S | ARM7TDMI | ARM7TDMI | ARM7TDMI |
| Frequency | 70MHz | 70MHz | 70MHz | 55MHz | 33.3MHz | 60MHz |
| Performance | 63 DMIPS | 63 DMIPS | 63 DMIPS | 50 DMIPS | 30 DMIPS | 54 DMIPS |
| Integrated Flash | 8K On chip | 16K On chip | 32K On chip | 32K On chip | 64K or 128K On chip | 256K or 512K In package |
| Flash I/F | 128 bits | 128 bits | 128 bits | 32 bits | 32 bits | 16 bits |
| SRAM | 2K | 4K | 8K | 8K | 16K | 32K |
| Ext Memory I/F | — | — | — | — | — | 16 bits |
| RT Clock | Yes | Yes | Yes | Yes | Yes | — |
| Timers | 4 + watchdog | 4 + watchdog | 4 + watchdog | 3 + watchdog | 7 + watchdog | 7 + watchdog |
| I²C | 2 | 2 | 2 | — | 1 | 1 |
| SPI | 2* | 2* | 2* | 1 | 2 | — |
| UART | 2 | 2 | 2 | 1 | 2 | 2 |
| GPIO | Up to 32 | Up to 32 | Up to 32 | — | Up to 40 | Up to 42 |
| Fast GPIO | Yes | Yes | Yes | — | — | — |
| Other | 8-ch 10-bit ADC | 8-ch 10-bit ADC | 8-ch 10-bit ADC | 8-ch 10-bit ADC, 2-Wire, SSC, PIO | 4-ch ADC, I²S | 4-ch 10-bit ADC, SSP |
| IC Process | 0.16µm | 0.16µm | 0.16µm | 0.18µm | 0.22µm | 0.22µm |
| Voltage (Core-I/O) | 1.8V/5.5V | 1.8V/5.5V | 1.8V/5.5V | 1.8V/5V | 2.25V/3.6V | 2.25V/3.6V |
| Power (typical) | 70mW† | 70mW† | 70mW† | 95mW | n/a | 290mW |
| Operating Temp | –40° to 85°C | –40° to 85°C | –40° to 85°C | –40° to 85°C | –40° to 85°C | –40° to 85°C |
| Package (size) | LQFP-48 7mm x 7mm PLCC-44 17mm x 17mm | LQFP-48 7mm x 7mm PLCC-44 17mm x 17mm | LQFP-48 7mm x 7mm PLCC-44 17mm x 17mm | LQFP-48 7mm x 7mm | WCSP-64‡ 4.84mm x 5.09mm TQFP-64‡ 10mm x 10mm | LQFP-144 20mm x 20mm LFBGA-144 11mm x 11mm |
| Availability | Samples 11/05 Prod. 12/05 | Samples 11/05 Prod. 12/05 | Samples 11/05 Prod. 12/05 | Now | Now | Now |
| Price (10K units) | $1.47 | $1.85 | $2.20 | $2.90 | $3.98 | $4.83 |

**Table 2.** This comparison pits the three new Philips MCUs against similar ARM7-based MCUs that are also competing against 8- and 16-bit chips. Many more such comparisons are possible, but these devices will be particularly close competitors. However, Philips has a distinct price advantage. *One SPI interface also supports SSP. †Philips estimates typical power consumption at 1mW/MHz. ‡The Oki ML67Q406x chips are also available in 84-pin LFBGA packages measuring 9mm × 9mm. (n/a = data not available)

Philips did cut a few corners to reach its low prices. The new MCUs have less internal SRAM and flash memory than competing devices have, and they provide fewer GPIO pins. For example, Oki's Advantage-series MCUs have two to eight times as much SRAM and two to four times as much flash, and they have at least 10 more GPIOs. Likewise, some Atmel MCUs have up to 256KB of SRAM.

The combination of relatively little internal memory and fewer GPIOs could be a problem for Philips in systems needing more memory, especially when a major reason for upgrading to a 32-bit MCU is greater memory capacity. The new Philips MCUs have only 32 GPIOs, maximum—in practice, fewer will be available if the chip uses its other serial interfaces. And like many MCUs in this class, the new Philips devices lack a controller for external memory. To attach external RAM, developers must press the GPIOs into service as a makeshift memory interface. Even if the external memory is only 16 bits wide, it would require half the maximum number of GPIO pins. Attaching 32-bit memory would use all the GPIOs, leaving none for other purposes.

On the plus side, the GPIOs that Philips does provide are uncommonly fast and well-suited for protocol conversions and other bit-banging jobs. Inevitably, all MCU vendors face the same trade-off: more I/Os require more pins and a larger package, inflating the manufacturing cost. Developers craving more memory can find plenty of other MCUs from Philips and competitors that make different trade-offs than do the LPC2101, LPC2102, and LPC2103. With so many ARM7-based MCUs to choose from, nobody seeking an upgrade to 32 bits should be starved for choices.