WDC Carries 6502 Flag into New Arenas

Little-Known Company Offers Low-Cost Chips, Licensed Designs

by Michael Slater

You don't hear much about the 6502 these days. The chip that was at the heart of the Apple II and Commodore 64, among others, was passed from MOS Technology to Synertek to Rockwell, and it might have faded entirely from the microprocessor scene if it were not for one determined individual—William D. Mensch, Jr.—and his tiny company, The Western Design Center (WDC). Today, this 10-person company offers several processors based on the 6502 architecture, and while you don't see it in the headlines, the chips are still used by the tens of millions in a wide range of products.

WDC's business model is unique among microprocessor companies: it is a fabless semiconductor company that readily licenses its designs to large customers. WDC sells chips in modest quantities (up to about 25,000 per year) to support low-volume applications. But its most important products are its chip designs: for high-volume users, WDC works with several foundries to match up the customer with a silicon supplier, and WDC's role from then onward is simply to collect royalties—typically 3% of the chip's selling price. This approach gives customers the freedom to choose their manufacturer.

	65C02S	65C816S	65C134S	65C265S
CPU core	8-bit	16-bit	8-bit	16-bit
Transistors	11,000	22,000	60,000	89,000
Std. prod. die size	6.5 mm^2	8.7 mm^2	15.1 mm^2	25.6 mm^2
CPU core size	2.0 mm^2	4.2 mm^2	2.0 mm^2	4.2 mm^2
Peak native MIPS	8	8	4	4
Max clock (3.3 V)	10 MHz	10 MHz	4 MHz	4 MHz
Max clock (5 V)	16 MHz	16 MHz	8 MHz	8 MHz
Power* (3.3 V)	33 mW	50 mW	26 mW	40 mW
Power* (5 V)	80 mW	120 mW	80 mW	120 mW
Supply voltage	1.0–6.0 V	1.0–6.0 V	1.0–6.0 V	1.0–6.0 V
Packages	PDIP-40, PLCC-44, PQFP-44	PDIP-40, PLCC-44, PQFP-44	PLCC-68, PQFP-80	PLCC-84, PQFP-100
Address range	64K	16M	64K	16M
ROM	none	none	4K	8K
RAM	none	none	192 bytes	576 bytes
UARTs	none	none	1	4
I/O lines	none	none	56	64
Timers	none	none	4	8
Tone generators	none	none	none	2
Price (10,000s)	$4.44	$5.58	$9.09	$17.64

Table 1. WDC offers two CPU cores, each of which is available stand-alone or as part of a single-chip microcomputer. Die sizes are shown for a 0.8-micron, two-layer-metal process. *Typical power at maximum clock rate.

WDC is 100% owned by its founder, president, and sole chip designer Bill Mensch. In an era of large design teams and sophisticated automatic layout tools, Mensch continues to design his own chips, by himself, with fully handcrafted layouts. Although this surely limits the volume and complexity of designs the company can produce, it has yielded some effective chip designs.

The company's product line began with the 65C02, a CMOS implementation of the venerable NMOS 6502. The 65C02 was used in the Apple IIc and in later production runs of the Apple IIe. In 1983, WDC extended the architecture to 16 bits with the 65C816, which was used in the Apple IIgs. A 32-bit extension, the 65C832, has been discussed for years but remains on the drawing board. Most recently, WDC has crafted a single-chip microcomputer, the 65C265, around the 65C816 core.

The Apple II line is no longer in production, but a host of other companies continue to use WDC's processors, some in very high volume. WDC estimates that well over 100 million 'C02 processors have been shipped, and that shipments currently run at a rate of about 25 million a year; the figures for the 'C816 are about half these amounts.

The 65C816 is at the heart of the Super Nintendo game machine, which alone is estimated to have sold over 30 million units. Another high-volume consumer-products maker is Franklin Electronic Publishing, which uses the 65C02 in its Language Translator and the 65C816 in its Digital Book System. Other WDC customers include General Instrument, Sanyo, ITT, AT&T GIS, Siemens Medical, Seiko, Teletronics, and Pioneer.

WDC first built its designs in a 2-micron CMOS process. Recent production has been in a 1.2-micron process, and all the designs will be moved to a 0.8-micron process by year-end. Sanyo is currently WDC's primary foundry for chips that it sells directly. Several foundries build chips for licensees; Ricoh is Nintendo's supplier.

WDC hopes that its CPUs can play a role in the PDA market, where their low cost and low power consumption are significant advantages. Although the chips can't match the performance of 32-bit processors, some fixed-function PDAs—Franklin's Digital Books, for example—don't need a lot of CPU horsepower.

Compact Designs Use Little Power

As Table 1 shows, WDC's designs are compact and low power. The CPU cores alone (without the pad ring), are very small: only 4.2 mm^2 for the 65C816. As you might expect for a hand-packed 16-bit CPU design, this

 © 1994 MicroDesign Resources

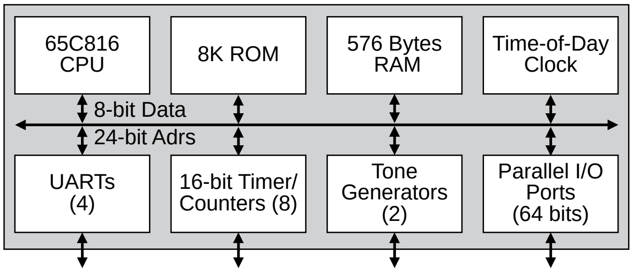

Figure 1. Western Design Center's 65C265 combines the 65C816 core with ROM, RAM, and I/O.

is smaller than even the tiniest 32-bit RISC cores, such as the ARM7 and Hitachi's SH, which are around 6 mm^2.

WDC's chips are also notable for their ability to run at low voltages—down to 1.0 V—and for their low power consumption. At 3.3 V with a 10-MHz clock, the 65C816 consumes only 50 mW typical, compared with 120 mW for an ARM700 with a 3.3-V supply and a 20-MHz clock. This comparison is not entirely fair, however, in that the ARM700 includes an on-chip cache and MMU, and it delivers much higher performance. If the ARM's clock were reduced to 10 MHz, its power consumption would drop to about 60 mW, and it would still outperform the 65C816.

The 65C134 and 65C265 extend the CPUs to form complete single-chip microcomputers. The 8-bit chip has 4 Kbytes of masked ROM, while the 16-bit version has double this amount. Figure 1 shows the block diagram of the 'C265, which includes four serial I/O ports.

Extending the 6502 Architecture

The 6502 instruction-set architecture closely resembles that of Motorola's pioneering 6800, with the primary difference being that the 6502 has two 8-bit index registers and one accumulator—a generally more useful configuration than the 6800's odd arrangement of two accumulators and one 16-bit index register. It has been called "the original RISC," and while it bears little resemblance to today's RISC architectures, it does have a pleasing simplicity. Indeed, WDC founder Bill Mensch attributes much of the processor's success to the fact that "engineers love this architecture."

The 6502 is not, however, without its weaknesses, and in WDC's first processor design, the 65C02, a number of them were remedied. The 'C02 has ten new instructions and two new addressing modes, and it also corrects some anomalous behavior of the condition code flags. One notable addition to the instruction set is the ability to push and pull (pop) the index registers—a deficiency that was a glaring hole in the original design.

The 65C816 extends the architecture to 16 bits while preserving 6502 compatibility through an emulation mode. After reset, the 'C816 acts just like a 'C02; the new features must be specifically enabled.

Price & Availability

WDC offers its chips in modest quantities to support new designs and limited-volume production. Pricing is shown in Table 1; all the chips are in production now in 1.2-micron versions, with 0.8-micron devices due to ship this fall. For high-volume production, the company will make arrangements for the chips to be purchased directly from a foundry. Licensing is royalty based and requires no up-front licensing fees.

The Mensch Computer is priced at $895 for developer units and will be available in August.

For more information, contact The Western Design Center (Mesa, Ariz) at 602.962.4545; fax 602.835.6442.

The 'C816 extends all the registers to 16 bits and the address bus to 24 bits. The larger address is supported by program and data bank registers, which are concatenated with the 16-bit program counter and index registers to produce 24-bit memory addresses. Among the nine new addressing modes are forms that allow a full 24-bit address to be encoded in an instruction, providing limited linear addressing over the full range (but the index registers are limited to 16 bits). There are also 28 new instructions.

Although it has a wider address bus to support the extended addressing range, the 'C816 sticks with the 8-bit data bus of its predecessor. Mensch believes that few applications require the higher bandwidth of a wider bus. Even the planned 'C832 will maintain an 8-bit data bus, with 32-bit-wide internal registers.

Into the Computer Business

WDC will soon introduce its first system-level product, the Mensch Computer. This system is based on the 65C816. It includes a 240 × 128–pixel LCD screen, capable of displaying graphics or 16 lines of 40 characters, and a PC-style keyboard, which uses a 'C134 for its controller. The system has a ROM-based monitor program, 32K of SRAM for user programs and data, and two PCMCIA slots. WDC's goal is to provide a simple, low-power, low-cost computer that is, in some sense, the spiritual successor to the Commodore 64.

The Mensch Computer comes with MenschWorks, a software package that provides simple text and graphics editors, a filer, and communications. Messages can be automatically exchanged between Mensch Computers via modem, and the system can be used as a terminal for accessing BBSs and on-line services.

Bill Mensch views the Mensch Computer as a "platform for creativity" to which others will add the software content. He believes that it could serve as the basis for a consumer computing device to be sold for under $500, but there is a big software gap between this goal and

 © 1994 MicroDesign Resources

The 6502's Long Path to The Western Design Center

The 6502 has followed a long and twisted path to its current home at WDC. It was created by a group of engineers who had worked at Motorola on the 6800 and its support chips but became disenchanted with their management, which wouldn't support the products the group wanted to pursue. In August 1974, a group of eight engineers and marketers, including Bill Mensch and Chuck Peddle, left Motorola to work for MOS Technology. MOS Technology was, at the time, the world's largest manufacturer of calculator chips, and it decided to move up to microprocessors.

Just over a year after the ex-Motorola team joined the company, MOS Technology premiered its first microprocessors—the 6501 and 6502—at Wescon in the fall of 1975. The architecture bore a striking resemblance to the 6800, with several enhancements, but it was not binary-compatible. The 6501 was pin-compatible with the 6800, whereas the 6502 added the innovation of an on-chip clock generator, which eliminated the need for the two-phase clock input but gave the chip a different pinout. Motorola promptly sued MOS Technology, and an out-of-court settlement was reached in which MOS Technology agreed to take the 6501 off the market but was free to sell the 6502.

The 6502 found its greatest ally in Steve Wozniak, who was just designing the Apple I. It was selected over its major competitors, the 6800 and 8080, not for any technical reason but simply on price: at a time when Motorola and Intel were charging $300 each for samples, MOS Technology chose to enable widespread experimentation by offering small quantities for the high-volume price of $25. For a couple of kids who were selling off possessions to raise money to build a computer, this was an overwhelming advantage.

Despite its success with the 6502, MOS Technology ran into financial trouble. One of its biggest customers was Jack Tramiel's Commodore, a leading calculator maker and creator of the Commodore Pet and Commodore 64, two successful 6502-based computers; Commodore acquired MOS Technology in 1976. Commodore later decided to get out of the semiconductor business, bringing to an end the first supplier of 6502 chips.

In the meantime, the 6502 had been licensed to Synertek and Rockwell. Synertek ultimately went out of business, leaving Rockwell as the only supplier of the original NMOS 6502. Rockwell used a derivative of the 6502 as a DSP in its 2400-baud modem chip set.

In 1977, Bill Mensch left MOS Technology (then a division of Commodore). After a stint at the consulting firm Integrated Circuit Engineering, reverse-engineering commercial microprocessors, he decided to start his own design company—at first, with an exclusive agreement to create chip designs for MOS Technology.

After designing a low-power calculator chip for MOS Technology, Mensch decided that he wanted to create a low-power, CMOS 6502 as his next project, but MOS Technology wasn't interested. He approached Rockwell, GTE, Synertek, and Mitel as well, but they all turned him down. In early 1981, he decided to design it on his own.

Working alone and without outside funding, Mensch designed the 65C02, adding a few new instructions while he created the low-power CMOS design. The chip has a different microarchitecture than the original 6502, using PLA-based microcode for instruction sequencing.

After completing the design, he went back to the same companies, offering to license it to them. This time, both GTE and Rockwell accepted, and Commodore promptly sued for theft of trade secrets. In another out-of-court settlement, Commodore settled in return for being granted the rights to the 65C02 for internal use at half the standard license fee. Synertek also licensed WDC's 65C02.

where the system is today. Possible applications include electronic dictionaries and organizers. Although the initial implementation is as a small desktop unit, its power consumption and chip count are low enough for it to be repackaged as a handheld device.

Finding a Role at the Low End

In an industry dominated by high-end, 32-bit designs, Bill Mensch hopes to show what can be accomplished with a low-cost, 16-bit system. His view is that many microprocessor-based systems have become needlessly complex, and that the key to making computing widespread is delivering it at a low cost.

The Mensch Computer is unlikely to succeed in most applications against the onslaught of low-cost PC-compatible systems. Although the PC is not as efficient in a pure engineering sense, its economy of scale is vastly greater, and this can easily swamp the cost savings that result from WDC's simpler design. The availability of a wide range of software is also an overwhelming advantage for any general-purpose application. Even for a custom, dedicated application, the development tools available for the PC give it a compelling advantage.

The high-profile PDA operating systems all require more powerful CPUs, so WDC's chips won't appear in general-purpose PDAs. In the consumer computing realm, WDC's processors seem best suited to fixed-function PDAs like Franklin's Digital Books. The low cost and low power consumption of the processors make them a good choice for applications where their performance is adequate. The ability to license the core design and to work directly with the chip foundry is also attractive for high-volume users. As for the Mensch Computer, its best opportunity appears to be as a prototype of a low-cost, dedicated information appliance, serving perhaps as an electronic mail terminal, organizer, or dictionary.♦

 © 1994 MicroDesign Resources