The Microcontroller BOOM

From 8 to 32 Bits in a Decade

By Stuart Cording (Elektor)

Entering the 2000s, 8-bit microcontrollers were the architecture of choice. In 1997, over 2 billion of the devices had been sold and, by 2006, it had reached 4 billion. However, by decade's end, 16-bit machines were overtaking 8-bit sales quantities, and Arm had more or less secured the path to 32-bit controllers. We also saw microcontrollers made accessible to the masses and a resurgence in home-brew audio projects thanks to MP3.

Entering the 2000s, the performance improvements of PCs and laptops continued unabated, and both Intel and AMD had broken the seemingly magical 1 GHz barrier. But the pursuit of Moore's Law, which had made this possible, was not only benefiting the PC industry. Microcontroller vendors could also use these advancements to pack more onto a piece of silicon than ever before.

The microcontroller (MCU) resulted from the semiconductor industry's quest to integrate ever-more computing capability into a single device. Texas Instrument's (TI) Gary Boone is generally recognized as the inventor of the MCU due to a patent submitted in 1977 [1]. It differentiated itself from the microprocessor by integrating memory and input/output (I/O) functions. The TMS1802NC, a 4-bit MCU targeting calculator applications, was actually launched six years earlier in 1971. TI went on to launch the TMS1000 series of MCUs in 1974 (**Figure 1**), with the devices featuring in TI's *Speak & Spell* and the futuristic *Big Trak* programmable vehicle. The 1970s gas crisis also triggered vehicle makers, such as Ford, to consider electronic control of engines to reduce fuel consumption. Their Electronic Engine Control (Ford EEC) used Toshiba's 12-bit TLCS-12 MCU, launched in 1973 [2].

By the 2000s, MCUs were well established in a wide range of control applications. Thanks to their flexibility, they had been used in electronics scales and clocks, metering systems, microwave ovens, and even gas (vehicle fuel) pumps. According to

2000 — Intel and AMD announced 1-GHz CPUs

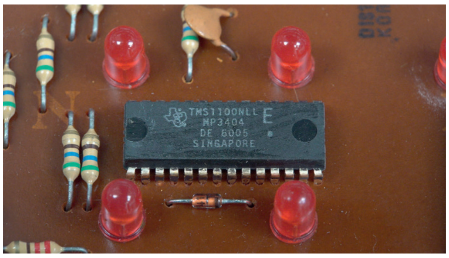
2000 — Steve Wozniak inducted into the National Inventors Hall of Fame industry expert Jim Turley, 8-bit processors made up 55% of sales in 2002, while 4-bit processors were still as common as 16-bit devices. 32-bit processors had only around 8% market share, of which 98% were in use in MCUs [3]. The remainder were Intel or AMD CPUs.

A Digital Montagues and Capulets

While Intel's 8051 (officially MCS-51) and Zilog's Z8 architectures were popular entering the decade, there was a real sense of rivalry between two specific 8-bit MCU families: Microchip and Atmel. Microchip had emerged from the microelectronics division of General Instrument, acquiring its Peripheral Interface Controller, or PIC, RISC (reduced instruction set computing) products. As the name suggests, it was initially conceived to perform I/O functions for a more powerful processor. The PIC16C84 revolutionized MCUs by integrating a reprogrammable memory based on EEPROM technology [4]. Computer owners could easily program the devices by bit-banging pins of a parallel or printer port attached to the programming interface of the PIC.

Due to its Harvard architecture, the PIC16 family has separate data and program memory busses (**Figure 2**). The SRAM stores 8-bit data, but the program memory stores the instructions as 14-bit words. With this strict division of the memories, programs cannot be executed from SRAM. Furthermore, static data held in program memory, such as strings of text, must be moved to the 'W register' (similar to an accumulator) before storing them in SRAM. Another quirk is the SRAM, which can only be addressed directly using a seven-bit address. Thus, SRAM is divided into blocks of 128 bytes, requiring a bank switch to move between banks. While assembler programmers can quickly get the hand of such MCUs eccentricities, the architecture made programming in C and developing C compilers more challenging.

This is where Atmel's AVR showed its advantage over the PIC architecture (**Figure 3**). Conceived by Alf-Egil Bogen and Vegard Wollan, students of the Norwegian Institute of Technology, it's generally thought that AVR stands for **A**lf and **V**egard's **R**ISC processor. The design was influenced by insights from the IAR Systems compiler developers in Sweden [5] to help ensure it could be efficiently programmed in C. Despite having separate program and data memory like the PIC, their modified Harvard architecture approach uses simplified access to static data stored in the



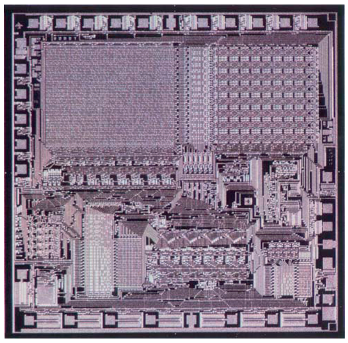


Figure 1: The TMS1000 series of MCUs from Texas Instruments put 4-bit performance into a range of products including kid's electronics toys.

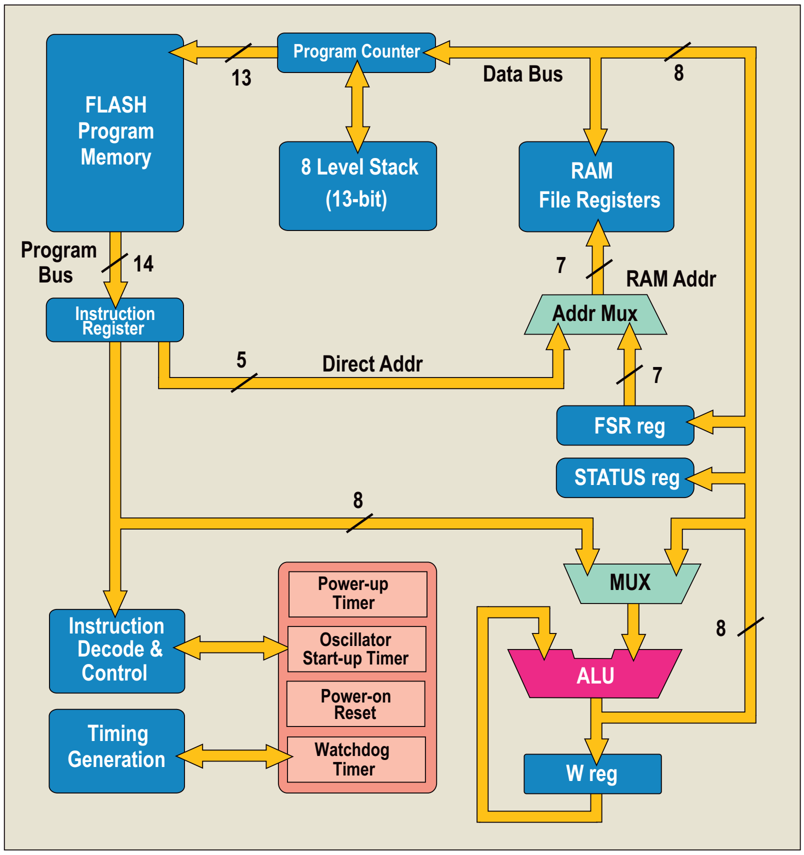


Figure 2: Developed in the 1970s, the 8-bit architecture of the PIC16 was still a staple of the Microchip MCU offering in the 2000s.

The Segway 2001 · *Napster bankruptcy* 2002 · *Ubuntu released* 2004

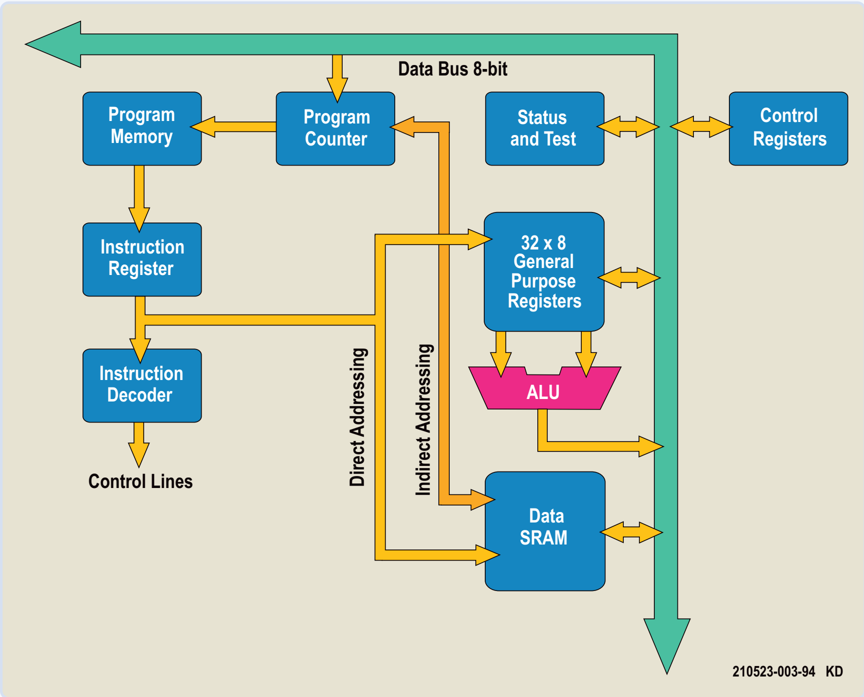


Figure 3: Atmel's 8-bit AVR architecture was better suited to programming in C than the PIC16.

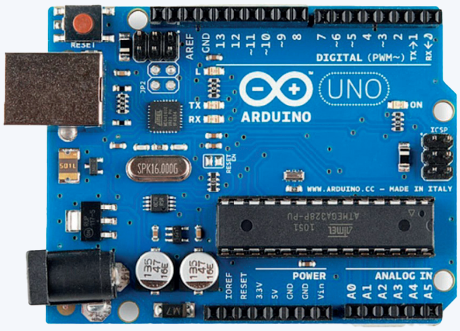


Figure 4: With the launch of Arduino, MCUs became accessible to hobbyists and artists alike.


Meer MP3-projecten

PORTABLES VOOR ZELFBOUW

Elektronica online

Enkele maanden geleden hebben we in deze rubriek al verschillende Internet-adressen gepresenteerd met MP3-projecten. Meestal werd daarbij uitgegaan van de hardware uit een oude PC. Maar het kan ook anders. Er zijn projecten waarbij je zelf een echt draagbare MP3-speler kunt bouwen.

Harry Baggen

Figure 5: Elektor's Harry Baggen reviews various home-brew MP3 projects online in 2001.

program memory. The availability of three 16-bit memory pointers, rather than the two planned initially, coupled with automatic incrementation, speeds up data copying tasks and makes support for C *struct* easier to implement in the compiler. Other improvements made the AVR more efficient at 16 and 32-bit arithmetic. They also had AVR Man [6].

Both Microchip and Atmel produced smaller 8-bit MCUs (PIC10/PIC12 and ATtiny) and ventured into more powerful MCUs too. Microchip delivered their C-friendlier 8-bit PIC18 in 2000, the 16-bit PIC24 and dsPIC families in 2001, and the 32-bit MIPS32 M4K-based PIC32 in 2007. Atmel launched the ATxmega 8-bit MCUs, with more SRAM and supporting higher clock frequencies, followed by their own 32-bit AVR32 series in 2006. In 2016 the rivalry became largely irrelevant as Microchip acquired Atmel for $3.6 billion [7].

Acorn Is Back!

The company that brought the BBC Micro to schools across the UK in the 1980s (see *The Battle of 8-Bit Home Computers*) lived on in the form of one of its subsidiaries, ARM Holdings. Known today simply as Arm (short for Acorn and then Advanced RISC Machines), it resulted from a joint venture between Acorn Computers, VLSI Technology, and Apple. With Apple providing the money and Acorn the people, the undertaking aimed to develop their RISC processor technology further [8]. This would result in the ARM 610, the brains of the Apple Newton personal digital assistant (PDA) in the 1990s.

In the 2000s, there was no shortage of 32-bit processors to choose from. However, designing a processor from scratch and developing the compiler and debugging tools to go with it was becoming increasingly costly. Additionally, with users typically programming in high-level languages (HLL) like C, the MCU's processor's performance was becoming less relevant. More critical was the quantity of memory, the available peripherals, and special functions such as low-power modes. Thus, licensing an entirely supported processor core looked increasingly attractive and allowed semiconductor vendors to concentrate on differentiating features, such as low power, wireless, and other peripherals.

Arm's strong portfolio of 32-bit ARM7 processors had been licensed for use in various MCUs and system-on-chip (SoC) devices. Atmel had licensed it for their AT91SAM7 series, which was available around 2008. In 2004, Arm announced their Cortex-M3 core optimized for the low-cost, energy-efficient demands of MCU designs. By 2009, Atmel had their ATSAM3U on the market, based on this core. Since then, almost all MCU vendors have opted to license one of the many Cortex-M cores, from NXP and STMicroelectronics to Infineon, Nordic, and TI.

YouTube founded 2005

Snapdragon processor 2007

MCUs for the Masses

Despite manufacturing the central component of control systems for decades, MCU vendors had been notably poor in delivering software for their chips. For sure, there were plenty of application notes and code examples, but, except for complicated interfaces such as USB or Ethernet, there was not much in the way of peripheral software libraries. For professional engineers, this was not a huge issue. However, if you were just trying to dip into the technology, there was a high chance of failure.

In 2003, Massimo Banzi was supervising a Masters's thesis project that aimed to create simple, low-cost tools that would allow non-engineers to build applications using Atmel's ATmega168. This resulted in *Wiring*, a codebase written in C++. It broke down the programming of the MCU into a *setup* function and a *loop* function. Control of I/O pins and communication via serial interfaces was supported with simple function calls that hid the register setup, oscillator configuration, and communication buffers' implementation. In 2005, Banzi and his team expanded Wiring to support the cheaper ATmega8, leading to the creation of Arduino [9] (**Figure 4**). In this edition, you can find an interview with David Cuartielles, Co-Founder of Arduino.

By pre-configuring hardware interfaces, Arduino simplified entry into the fascinating world of embedded systems and electronics. It has also created a wealth of expansion boards (shields) that are delivered with software and clones that can all be programmed in the same manner using the same development environment.

Musical MCUs

2001 also saw the launch of the iPod, the mini music player that built on the growing success of MP3 audio compression. Reigniting the 'I'll make it myself' spirit, many hobbyists developed their own MP3 players, storing hours of music on CompactFlash (CF) cards or hard disk drives. While simple 8-bit MCUs were not powerful enough to decode MP3 files, a range of decoders, like the VS1001K [10], could. However, an 8-bit MCU was ideal for handling the storage-drive interface, LCD display, and input buttons.

Elektor's very own Harry Baggen (**Figure 5**) reviewed a collection of such home-brew projects in the June 2001 issue of *Elektuur*. Paul Stoffregen's MP3 Player used the 87C52, an 80C51 derivative, together with the STA013 decoder chip [11]. YAMPP (Yet Another MP3 Player) was Eric Guérard's version, combining the VS1001K decoder with an ATMEGA162 [12].

By the end of the decade, the first iPhone had been launched, opening up a new world of always-on connectivity and apps. Not surprisingly, this got people thinking about how to connect MCUs to smartphones. ◄

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About the Author

Stuart Cording is an engineer and journalist who initially dismissed the Arduino and regrets it today. With more than 25 years of experience in the electronics industry, you can read many of his Elektor articles at www.elektormagazine.com/cording.

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