Until 1993, industrial electronics was dominated by analog ICs and discrete semiconductors. Since then, microcontrollers, microprocessors and DSPs have claimed the largest share of semiconductor sales in the industrial electronics market and even outpaced memories in recording the highest growth rates.

Microcontrollers

Powerful 8 and 16-bit microcontrollers are the key to tapping the full potential of electronic controls for automated machinery and systems. Over the next few years, industrial electronics will be one of the fastest-growing sectors of the semiconductor market. Here the CAN bus in particular, with its exceptional flexibility, is emerging as the de facto standard for industrial networking.

Segments of the industrial electronics market

- Electronic drives with all subsegments (e.g., pumps, elevator controllers, etc.)
- Stored program controls
- Automation
- Domestic appliances
- Meters (gas, water, electricity, etc.)
- Heating, ventilation and airconditioning

C166 (16-bit) families of microcontrollers cater to all industrial applications (Tables 1 and 2). Plans are to extend these product lines with core upgrades and a new 32-bit architecture.

Microcontrollers from both the C500 and C166 families have been successfully used for years in the industrial sector. They include the C515, the 80C535, the 80C517 or even the C501 – a derivative compatible with the 80C32 industry standard. These products make up the core of many industrial applications. In the C166 family, the 80C166, C167, C167CR and C165 microcontrollers are used in stored program controls and drive controls.

Apart from standard industrial control tasks, this market presents some unconventional applications. The C513, for instance, is used in a fish detector, while the 80C166 is integrated into the drive control of an electric golf cart. The microcontroller matches the torque to the terrain of the golf course and thus ensures constant cart speed. The original member of the C166 family – the 80C166 – is also

Features of the C504

The C504 8-bit microcontroller with 16K bytes of ROM or OTP and 512 bytes of RAM has been optimized in terms of RF emissions and power consumption. Its core and peripherals feature:

- self-calibrating, 8-channel 10-bit A/D converter
- power-down mode which can be woken up by an interrupt
- enhanced hooks on-chip emulation support logic
- programmable watchdog timer
- oscillator watchdog
- optional ROM protection
- fast power-on reset
- four 8-bit ports
- three 16-bit timers/counters
- 8-bit USART
- 12 interrupt sources with two priority levels

The chip is available in an MQFP-44 package for temperature ranges from 0 to 70 °C and from -40 to 125 °C. Maximum clock frequency is 40 MHz.
used to control a wide range of vending machines.

**C504 with OTP memory – the perfect choice for drive controls**

The special on-chip peripherals of the C504 make this 8-bit microcontroller ideal for drive controls. The C504 is completely upwardly compatible with the basic C501 type and matches the 80C32 industrial standard.

As well as in established versions, the C504 – in either ROM-coded (16k-byte ROM) or ROM-less versions – is the first Siemens microcontroller to be offered in OTP (one-time programmable) technology with a 16k-byte OTP memory and 512 bytes of RAM. This gives customers exceptional flexibility. A minimum of a few thousand units per code (program) is needed for profitable production of mask-programmable microcontrollers. The self-programming capability of the C504 OTP version gives equipment manufacturers complete freedom to customize software.

Thanks to OTP technology, microcontrollers are evolving more and more into standard components that can be supplied in very small and very large quantities alike. OTP versions will be available in future for all new controllers in the C500 family.

The key component of the drive control periphery is a 3+3-channel capture-compare unit (CCU) designed to generate a six-channel pulse width modulation (PWM) signal. With resolution up to 50 ns and a dead time programmable in two modes, it covers all PWM functions essential to drive control applications. These functions comprise standard PWM (edge-aligned, possible with both compare timers) and symmetrical PWM (center-aligned, possible with compare timer 1). The microcontroller may be operated with an external trap signal to safeguard the system. The CCU also supports the block commutation mode.

Features like these make the C504 suitable for all types of frequency converters, for inverters and for drive applications where the frequency is regulated via voltage and current. So it can be used just as effectively in AC as in DC motors. In DC applications, the C504 controls series-wound motors, shunt motors and externally excited machines. In AC machines, it controls rotary field, synchronous, asynchronous and reluctance motors as well as stepper motors (both unipolar and bipolar). Application notes documenting the versatility and utility of the C504 describe, for example, a stepper motor configuration or control of a three-phase brushless DC motor. They can be obtained via the Internet, from Siemens sales offices or distributors. Siemens’ Tool Partners support the C504 with a complete development package and programming tools for OTP technology. A low-cost starter kit is also available for the C504.

### 80C5xx family: up to 68 I/O lines, PWM output (21 channels)

<table>
<thead>
<tr>
<th>Type</th>
<th>Max. clock rate</th>
<th>ROM (Byte)</th>
<th>RAM incl. XRAM (Byte)</th>
<th>ADC inputs/resolution</th>
<th>Timer (16-Bit)</th>
<th>Serials I/O</th>
<th>Others</th>
<th>Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAB 80C515</td>
<td>20</td>
<td>8k</td>
<td>256</td>
<td>Prog.REF 8/10</td>
<td>3</td>
<td>UART</td>
<td>4-ch. PWM, WDU</td>
<td>P-LCC-68</td>
</tr>
<tr>
<td>SAB 80C535</td>
<td>20</td>
<td>ROM/ROM</td>
<td>256</td>
<td>Prog.REF 8/10</td>
<td>3</td>
<td>UART</td>
<td>4-ch. PWM, WDU</td>
<td>P-LCC-68</td>
</tr>
<tr>
<td>SAB 80C515A</td>
<td>18</td>
<td>ROM/ROM</td>
<td>1280</td>
<td>8/10</td>
<td>3</td>
<td>UART</td>
<td>EEPROM version available 4-ch. PWM, WDU</td>
<td>P-LCC-68</td>
</tr>
<tr>
<td>SAB 80C515A-5</td>
<td>18</td>
<td>32k</td>
<td>1280</td>
<td>8/10</td>
<td>3</td>
<td>UART</td>
<td>EEPROM version available 4-ch. PWM, WDU</td>
<td>P-LCC-68</td>
</tr>
<tr>
<td>SAB 80C517</td>
<td>16</td>
<td>8k</td>
<td>256</td>
<td>Prog.REF 12/8</td>
<td>4</td>
<td>UART</td>
<td>21-ch. PWM, WDU</td>
<td>P-LCC-64</td>
</tr>
<tr>
<td>SAB 80C537</td>
<td>16</td>
<td>ROM/ROM</td>
<td>256</td>
<td>Prog.REF 12/8</td>
<td>4</td>
<td>UART</td>
<td>21-ch. PWM, WDU</td>
<td>P-LCC-64</td>
</tr>
<tr>
<td>SAB 80C517A</td>
<td>18</td>
<td>ROM/ROM</td>
<td>2304</td>
<td>12/10</td>
<td>4</td>
<td>UART</td>
<td>EEPROM version available, WDU 21-ch. PWM, hardware power-down</td>
<td>P-LCC-64</td>
</tr>
<tr>
<td>SAB 80C517A-5</td>
<td>18</td>
<td>32k</td>
<td>2304</td>
<td>12/10</td>
<td>4</td>
<td>UART</td>
<td>EEPROM version available, WDU 21-ch. PWM, hardware power-down</td>
<td>P-LCC-64</td>
</tr>
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</table>

**Table 1** 8-bit microcontrollers of the C500 and 80C5xx families can be used in all fields of industrial electronics
drive and control segment of the industrial electronics market.

**Full-CAN controller integrated**

A full-CAN controller (2.0B active) is integrated into the C505C. This microcontroller chip, which is compatible with the C501/80C32, thus replaces current two-chip solutions. The CAN module implanted in the C505C is equivalent to those of the C167CR and C515C. It operates to the 2.0B active standard and can be used in both standard CAN (2048 message identifier) and extended CAN (>536 million message identifier) modes.

For industrial electronics, CAN offers fast and reliable communication and networking options via a simple two-wire line (see sidebar The CAN protocol). This applies first and foremost to networking of all kinds of automation equipment, from sensors to drives. CAN controllers can also link various intelligent subsystems in production lines (Fig. 2), such as printing presses or paper and textile machinery. The CAN protocol is also used for initialization functions, for uploading/downloading programs and parameters, for diagnosis, and for comparing actual with specified control data. Other applications include transportation systems, heater controls, air conditioning systems, lighting systems, security and surveillance systems, elevators and escalators. With its unique versatility, the CAN bus is well on the way to becoming the standard bus for networking in industrial electronics.

### 16-bit performance for the price of an 8-bit microcontroller

The C161 derivatives enable customers whose 8-bit microcontrollers have reached their performance limits to migrate to 16-bit technology easily and inexpensively. The C161 offers 16-bit performance in a market dominated up to now by 8/16-bit hybrid architectures.

The three latest 16-bit microcontrollers – the C161V, C161K and C1610 – are based on the C166 CPU. This architecture combines the advantages of RISC and CISC processors and provides excellent peripheral functionality with an I/O structure. All

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### Low-cost networking with the C505C

Samples of this low-cost 8-bit microcontroller have been available since February. The C505C is pin-compatible with the C501, C511/C513, C502 and C504 types of the C500 family. It features:

- on-chip CAN controller
- 16K bytes of ROM (later also with 32K ROM and as OTP version)
- 512 bytes of RAM
- C500 CPU with eight data pointers
- 12 interrupt sources with four priority levels
- 2 to 20 MHz external clock
- powerful A/D converter
- fast power-on reset
- deactivation option for ALE signal
- three power-saving modes
- peripherals familiar from the C504, but without CCU

The C505C is available in the MQFP-44 package for all temperature ranges.

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### Table 2 16-bit microcontrollers are the answer for applications demanding higher performance

<table>
<thead>
<tr>
<th>Members of C166 family</th>
<th>Type</th>
<th>Max. CPU clock</th>
<th>Oscillator</th>
<th>Instruction cycle time</th>
<th>ROM (Byte)</th>
<th>RAM including XROM</th>
<th>ADC 10-bit resolution</th>
<th>Timers + counter + units</th>
<th>Serial I/O</th>
<th>Packaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-chip hardware functions: up to 63 I/O lines, power-down, watchdog, bootstr. loader, 4 MB address space</td>
<td>C166</td>
<td>20 MHz</td>
<td>direct</td>
<td>–</td>
<td>2 KB</td>
<td>–</td>
<td>3</td>
<td>5</td>
<td>USART</td>
<td>P-MOPF-40</td>
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<tr>
<td>On-chip hardware functions: up to 77 I/O lines, power-down, watchdog, bootstr. loader, 16 MB address space</td>
<td>C165</td>
<td>20 MHz</td>
<td>prec. input</td>
<td>–</td>
<td>2 KB</td>
<td>–</td>
<td>5</td>
<td>7</td>
<td>USART</td>
<td>P-TDFP-100</td>
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<tr>
<td>On-chip hardware functions: up to 77 I/O lines, power-down, watchdog, bootstr. loader, 16 MB address space</td>
<td>C166</td>
<td>20 MHz</td>
<td>direct</td>
<td>–</td>
<td>2 KB</td>
<td>–</td>
<td>5</td>
<td>7</td>
<td>USART</td>
<td>P-TDFP-100</td>
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<tr>
<td>On-chip hardware functions: up to 78 I/O lines, capture-compare unit (16 channels), power-down, watchdog, bootstr. loader, 256 KB address space</td>
<td>C167</td>
<td>20 MHz</td>
<td>prec. input</td>
<td>–</td>
<td>2 KB</td>
<td>10</td>
<td>9</td>
<td>USART</td>
<td>P-MOPF-144</td>
<td></td>
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</tbody>
</table>

* In preparation
versions are currently available as ROM-less types in MQFP-80 packages. The C161V and C161K have 1K bytes of on-chip RAM, the C161O 2K bytes. The three models also differ in the number of chip-select signals, in the multiplexed or demultiplexed external address/data bus, in their power-saving modes and in the number of priority levels in the interrupt system. They are available for the standard temperature range from 0 to 70 °C and for the extended range from -40 to +85 °C. The C161 versions are suitable for all industrial control applications where computing power and real-time performance are critical. The C161 is also a good choice for multichip solutions using external A/D converters or ASICs. Its processor-oriented structure supports external peripherals and minimizes system costs. What’s more, the performance leap from 8 to 16-bits makes it possible to emulate peripheral modules with software and thus reduce CPU load. Further derivatives with extended on-chip peripherals will follow.

**Complete development package**

A complete, tried-and-tested hardware and software development package is available from Siemens’ international Tool Partners for all components of the C500 and C166 microcontroller families. It includes:
- compilers,
- macro-assemblers,
- linkers,
- locators,
- simulators
- HLL debuggers,
- RTOS,
- in-circuit emulators,
- industrial boards, and
- ongoing development support.

Starter kits are also available for these new products. Together with the low-cost tools already described, they enable users to enter the world of microcontrollers with maximum convenience and minimum expense.

**The CAN protocol**

The CAN (controller area network) protocol developed by Bosch in the mid-80s is an asynchronous, serial bus with a linear bus structure. It offers users numerous advantages:
- High-volume production for automotive and industrial applications leads to a very attractive price structure.
- As CAN is standardized to ISO-DIS 11898, ISO-DIS 11519-1 and various SAE standards, all CAN systems can communicate with each other. Troubleshooting mechanisms implemented in CAN guarantee a high degree of reliability.
- CAN’s maximum transmission rate of 1 Mbit/s over a bus length of 40 meters (cable length) ensures fast data transfer. A transmission rate of 40 kbit/s is even possible over a bus length of one kilometer. The number of nodes is not limited by the protocol. CAN nodes can also be easily connected or separated. This flexibility makes the CAN protocol suitable for the widest variety of applications.
- Thanks to its short message length (0 to 8 data bytes per message), the CAN bus offers real-time performance.
- CAN’s multimaster capability means that every CAN node can use the bus. Faulty nodes do not interrupt bus communication, but are simply detached from it.
- All CAN nodes can receive the same data simultaneously, and messages can be sent to one or several nodes.