counters, as a single 8-bit counter with a 5-bit prescaler, and as a single 8-bit counter with an 8-bit reload value. The first two modes mentioned are straightforward: the timers count from 0 to either 65,535 (16-bit) or 255 (8-bit) before rolling over and perhaps generating an interrupt. The third mode is similar, but the 8-bit counter increments only once every 32 machine cycles. The 5-bit (2^5 = 32) prescaler functions as a divider ahead of the main counter. Apparently, the main reason for including this mode was to retain function compatibility with the 8048's prescaled timer. The fourth mode is interesting, because the 8-bit counter is reloaded with an arbitrary 8-bit value rather than 0 after reaching its terminal count value (255). When operated in timer mode, this feature enables the timer to synthesize a wide range of low-frequency periodic events. One very useful periodic event is an RS-232 bit-rate generator. A commonly observed 8051 operating frequency is 11.0592 MHz. When this frequency is divided by 12, a count increment rate of 921.6 kHz is obtained. Further dividing this frequency by divisors such as 96 or 384 yields the standard RS-232 bit rates 9.6 kbps and 2.4 kbps. A divisor of 384 cannot be implemented in an 8-bit counter. Instead, a selectable ÷16 or ÷32 counter is present in the serial port logic that generates the final serial bit rate.

The 8051's on-board serial port implements basic synchronous or asynchronous transmit and receive shift-register functionality but does not incorporate hardware handshaking of the type used in RS-232 communications. Serial transmission is initiated by writing the desired data to a transmit register. Incoming data is placed into a receive register, and an interrupt can be triggered to invoke a serial port ISR. The serial port can be configured in one of four modes, two of which are higher-frequency fixed bit rates, and two of which are lower-frequency variable bit rates established by the rollover characteristics of an on-board timer. Mode 0 implements a synchronous serial interface where the "receive data" pin is actually bidirectional and a transmit clock is emitted on the "transmit data" pin. This mode operates on 8-bit data and a fixed bit rate of 1/12 the operating frequency.

Mode 1 implements an asynchronous transmit/receive serial port where ten bits are exchanged for every byte: a start bit, eight data bits, and a stop bit. The bit-rate is variable according to a timer rollover rate. Mode 3 is very similar to mode 1, with the added feature that a ninth data bit is added to each byte. This extra data bit can be used for parity in an RS-232 configuration or for another application-specific purpose. These two modes can be used to implement an RS-232 serial port without hardware handshaking. Software-assisted hardware handshaking could be added using general I/O pins on the 8051. Mode 2 is identical to mode 3 except for its fixed bit rate at either 1/32 or 1/64 the operating frequency. Modes 1 and 3 can be made to operate at standard RS-232 bit rates from 19.2 kbps on downward with the aforementioned 11.0592 MHz operating frequency. A selectable ÷16 or ÷32 counter within the serial port logic combines with the timer rollover to achieve the desired serial bit rate.

Intel's 8051 architecture has been designed into countless applications in which a small, embedded computer is necessary to regulate a particular process. The original 40-pin devices are still commonly used and found in distributors' warehouses, but a host of newer devices are popular as well. Some of these variants are larger and more capable than the original and include more I/O ports, onboard peripherals, and memory. Some variants have taken the opposite direction and are available in much smaller packages (e.g., 20 pins) with low power consumption for battery-powered applications. There are even special versions of the 8051 that are radiation hardened for space and military applications. Companies that manufacture 8051 variants include Atmel, Maxim (formerly Dallas Semiconductor), and Philips. Atmel manufactures a line of small, low-power 8051 products. Maxim offers a selection of high-speed 8051 microcontrollers that run at up to 33 MHz with a 4-cycle architecture, as compared to 12 in the original 8051. Philips has a broad 8051 product line with a variety of peripherals to suit many individual applications.

The mature ROM-less 8031/8032 members of the 8051 family can be ordered through many mail order retail electronics outlets for only a few dollars apiece. The equally mature 8751/8752 EPROM devices can also be found from many of these same sources, though at a higher price as a result of the expense of the ceramic DIP in which they are most often found. More specialized 8051 variants may be available only through manufacturers' authorized distributors.

6.4 MICROCHIP PIC® MICROCONTROLLER FAMILY

By the late 1980s, microcontrollers and certain microprocessors were well established in embedded control applications. Despite advances in technology, not many devices could simultaneously address the needs for low power, moderate processing throughput, very small packages, and diverse integrated peripherals. Microchip Technology began offering a family of small peripheral interface controller (PIC®)* devices in the early 1990s that addressed all four of these needs. Microchip developed the compact PIC architecture based on a *reduced instruction set core* (RISC) microprocessor. The chips commonly run at up to 20 MHz and execute one instruction every machine cycle (four clock cycles)—except branches that consume two cycles. The key concept behind the PIC family is simplicity. The original 16C5x family, shown in Fig. 6.7, implements a 33-instruction microprocessor core with a single working register (accumulator), W, and only a two-entry subroutine stack. These devices contain as little as 25 bytes of RAM and 512 bytes of ROM, and some are housed in an 18-pin package that can be smaller than a fingernail. The PIC devices are not expandable via an external bus, further saving logic. This minimal architecture is what enables relatively high performance processing with low power consumption in a tiny package. Low-power operation is also coupled with a wide operating voltage range (2 to 6.25 V), further simplifying certain systems by not always requiring voltage regulation circuits.

No interrupt feature is included, which is a common criticism of the architecture; this was fixed in subsequent PIC microcontroller variants. PIC devices are, in general, fully static, meaning that they can operate at an arbitrarily low frequency; 32 kHz is sometimes used in very power-sensitive appli-

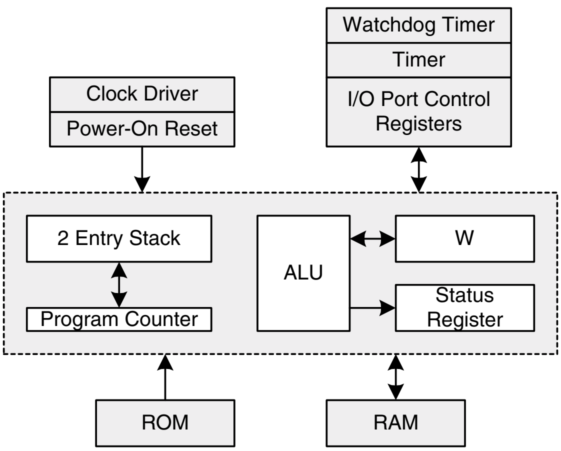

FIGURE 6.7 PIC microcontroller 16C5x architecture.

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