passes. These DSOs take relatively few samples on each pass, which is why a signal must be repetitive so that multiple passes are sampling essentially the same waveform. Sampling resolution is a closely related characteristic. It is common to find DSOs with eight-bit resolution, which is adequate for many digital probing needs because of these signals' binary nature. Certain analog applications may require finer resolution to take proper measurements, and such improvements come at a cost.

A relative of the oscilloscope is the logic analyzer, a device that is intended for purely digital test applications. Like a DSO, a logic analyzer captures signals at high sampling rates as they occur and then freezes them for human analysis for an arbitrarily long time. The principal differences are that a logic analyzer captures single-bit samples and, consequently, is able to work with dozens or hundreds of channels at the same time. High channel count enables a logic analyzer to capture complex buses in their entirety so that a complete picture of a bus's digital state can be displayed. An oscilloscope can show that a write-enable is coinciding with a chip-select. A logic analyzer can also show the specific data and address that are being transacted during that write operation. Logic analyzers are characterized by sampling rate, the number of channels supported, buffer depth, and triggering capabilities. At a basic level, a logic analyzer contains a large memory into which new samples are loaded every clock cycle. Faster, wider, and deeper memories cost more money than slower, narrower, shallower memories.

An important logic analyzer feature is its triggering capability. A simple type of triggering is one in which the logic analyzer waits for a specific pattern to present itself and then fills its entire buffer with the data following the pattern occurrence. If a serial port driver is being debugged, the logic analyzer trigger might be the address of a control register in the UART. Probing all signals on the microprocessor bus with the logic analyzer enables long instruction sequences to be correlated with hardware behavior to determine where a fault lies. When the microprocessor accesses a UART register, the logic analyzer triggers and stores all subsequent state information until the analyzer's memory is filled. The trigger point can usually be configured at an arbitrary offset in the analyzer memory. If the beginning of memory is chosen, the result is that the state following the trigger is captured. If the end of memory is chosen, the state leading up to the trigger is captured. Choosing a middle memory location captures the state both before and after the trigger event. Each debugging effort is best assisted by choosing a specific triggering option. If, for example, the wrong data is being transmitted from the UART, the state prior to the trigger event is likely to be useful, because it would show the microprocessor's instructions that presumably caused the data error. If, instead, the microprocessor appears to crash after transmitting data, the state after the trigger event may be more useful.

More complex digital buses and algorithms benefit from more powerful triggering capabilities. Many logic analyzers can trigger after a number of occurrences of the same pattern are observed or after several predetermined patterns are observed in specific sequences. In the previous UART debugging example, incorrect results may not occur until after many bytes have been transmitted. Alternatively, incorrect results may occur only after a certain byte sequence has been sent. A good analyzer can be configured to trigger on arbitrary combinations of patterns and occurrences.

APPENDIX A
Further Education

One of the exciting aspects of electrical engineering is that the state of the art changes quickly. Consequently, there is always the need to learn about new technologies, methods, and components. The modern engineer is fortunate to have a multitude of educational resources from which to draw. The Internet has made technical information more accessible than ever to anyone with a modem. Educational resources for engineers include

- Trade publications and subscription periodicals
- Technical books
- Manufacturers' web sites and publications
- Third-party web sites
- Colleagues and conferences

Trade publications and other periodicals are a good way to keep aware of current trends in the industry, because articles are often written about new and interesting technologies. Even advertisements provide an education, because manufacturers' claims can be compared against each other and against information acquired elsewhere. Many trade publications are funded by advertisements and can therefore offer free subscriptions to qualified subscribers with relevant professional responsibilities and technical needs. The following periodicals are recommended by the author:

- *Circuit Cellar* (paid subscription). The focus is on embedded systems with articles describing real implementations and discussions of how to make practical systems work.
- *EDN* and *Electronics Design* (free subscriptions). Articles are written by staff editors and professional engineers on topics from current trends to specific design implementation techniques and technical advice.
- *EE Times* (free subscription). This is a general electronics industry weekly news with articles on current trends and new technologies.

Technical books are available on practically every aspect of engineering. Chances are that you are already aware of this option, because you are reading this book right now! The following books are recommended as references for various topics that arise in digital electrical engineering:

- Computer architecture—*Computer Organization and Design: The Hardware/Software Interface,* David A. Patterson and John L. Hennessy, Morgan Kauffman.
- Signal integrity and PCB design—*High-Speed Digital Design: A Handbook of Black-Magic,* Howard W. Johnson and Martin Graham, Prentice Hall.