Standard bit rates are 2^N multiples of 300 bps. In the 1970s, 300 bps serial links were common. During the 1980s, links went from 1,200 to 2,400, to 9,600 bps. RS-232 data links now operate at speeds from 19.2 to 153.6 kbps. Standard RS-232 bit rates are typically divided down from reference clocks such as 1.843, 3.6864, 6.144, and 11.0592 MHz. This explains why many microprocessors operate at oddball frequencies instead of even speeds such as 5, 10, or 12 MHz.

RS-232 defines signals from two different perspectives: *data communications equipment* (DCE) and *data terminal equipment* (DTE). DCE/DTE terminology evolved in the early days of computing when the common configuration was to have a dumb terminal attached to a modem of some sort to enable communication with a mainframe computer in the next room or building. A person would sit at the DTE and communicate via the DCE. Therefore, in the early 1960s, it made perfect sense to create a communication standard that specifically addressed this common configuration. By defining a set of DTE and DCE signals, not only could terminal and modem engineers design compatible systems, but cabling would be very simple: just wire each DTE signal straight through to each DCE signal. To further reduce confusion, the DTE was specified as a male DB-25 and the DCE as a female DB-25. Aside from transmit and receive data, hardware handshaking signals distinguish DCE from DTE. Some signals are specific to modems such as *carrier detect* and *ring indicator* and are still used today in many modem applications.

The principle behind RS-232 hardware handshaking is fairly simple: the DTE and DCE indicate their operational status and ability to accept data. The four main handshaking signals are *request to send* (RTS), *clear to send* (CTS), *data terminal ready* (DTR), and *data set ready* (DSR). DTR/DSR enable the DTE and DCE to signal that they are both operational. The DTE asserts DTR, which is sensed by the DCE and vice versa with DSR. RTS/CTS enable actual data transfer. RTS is asserted by the DTE to signal that the DCE can send it data. CTS is asserted by the DCE to signal the DTE that it can send data. In the case of a modem, carrier detect is asserted to signal an active connection, and ring indicator is asserted when the telephone line rings, signaling that the DTE can instruct the modem to answer the phone.

In a *null-modem* configuration, two DTEs are connected, and each considers DTR and RTS outputs and DSR and CTS inputs. This is solved by swapping DTR/DSR and RTS/CTS so that one DTE's DTR drives the other's DSR, and so on. The unidirectional carrier detect is also connected to the DTR signal at the other end (DSR at the local end) to provide positive "carrier detect" when the terminal ready signal is asserted.

Table 5.2 lists the full set of RS-232 signals with the convention that signals are named relative to the DTE. Most of the original 25 defined RS-232 signals are rarely used, as evidenced by the popularity of the smaller DE9 connector. Furthermore, a minimal RS-232 serial link can be implemented with only three wires: transmit, receive, and ground. In more recent times, the DTE/DCE distinction has created confusion in more than one engineering department, because the definitions of terminal and modem do not always hold in the more varied modern digital systems context. Often, all RS-232 ports are configured as DTE, and special crossover, or null-modem, cables are used to properly connect two DTEs. While varying subsets of the DTE pin assignment can be found in many systems, there is still a place for the original DTE/DCE configuration. It is rare, however, to find the DB25 pins that are not implemented in the DE9 actually put to use.

Not all RS-232 interfaces are configured for hardware handshaking. Some may ignore these signals entirely, and others require that these signals be tied off to the appropriate logic levels so that neither end of the link gets confused and believes that the other is preventing it from sending data. Using a software flow control mechanism can eliminate the need for the aforementioned hardware handshaking signals and reduce the RS-232 link to its three basic wires: transmit, receive, and ground. These many permutations of DTE/DCE and various degrees of handshaking are what cause substantial grief to many engineers and technicians as they build and set up RS-232 equipment. There is a healthy industry built around the common RS-232 configuration problems. *Breakout*

TABLE 5.2 RS-232 DTE Pin Assignments

DB25 DTE	DE9 DTE	Signal	Direction: DTE/DCE	Description
1	–	Shield	⇔	Shield/chassis ground
2	3	TXD	⇒	Transmit data
3	2	RXD	⇐	Receive data
4	7	RTS	⇒	Request to send
5	8	CTS	⇐	Clear to send
6	6	DSR	⇐	Data set ready
7	5	Ground	⇔	Signal ground
8	1	DCD	⇐	Data carrier detect
9	–	+V	⇔	Power
10	–	–V	⇔	Power return
11	–			Unused
12	–	SCF	⇐	Secondary line detect
13	–	SCB	⇐	Secondary CTS
14	–	SBA	⇒	Secondary TXD
15	–	DB	⇐	DCE element timing
16	–	SBB	⇐	Secondary RXD
17	–	DD	⇐	Receiver element timing
18	–			Unused/local-loopback
19	–	SCA	⇒	Secondary RTS
20	4	DTR	⇒	Data terminal ready
21	–	CQ	⇐	Signal quality detect
22	9	RI	⇐	Ring indicator
23	–	CH/CI	⇔	Data rate detect
24	–	DA	⇒	Transmitter element timing
25	–			Unused/test-mode

boxes can be purchased that consist of jumper wires, switches, and LEDs to help troubleshoot RS-232 connectivity problems by reconfiguring interfaces on the fly as the LEDs indicate which signals are active at any given moment. As a result of the male/female gender differences of various DB25/DE9 connectors, there are often cabling problems for which one needs to connect two males or two females together. Once again, the industry has responded by providing a broad array of gender-matching cables and adapters. On a conceptual level, these problems are simple; in practice, the per-