In this logic circuit, the inverted output of the state flop, U1B, is used as the *state* bit to compensate for the 7451's NOR function. The unused *clr_* and *b* pins of U3 are connected to +5 V to render them neutral on the shift register's behavior. The shift register will not clear itself, because *clr_* is active-low and, similarly, the internal input AND-gate that combines *a* and *b*, will be logically bypassed by tying *b* to logic 1. The parallel byte output of this serial receiver is designated *Dout[7:0]* and is formed by grouping the eight outputs of the shift register into a single bus. One common notation for assigning members of a bus is to connect each individual member to a thicker line with some type of *bus-ripper* line. The bus ripper is often drawn in the schematic diagram as mitered or curved at the bus end to make its function more visually apparent.

Designing an accompanying serial transmitter follows a very similar design process to the preceding discussion. It is left as an exercise to the reader.

## 2.6 COMMON VARIANTS OF THE 7400 FAMILY

In the 1970s and 1980s, the 7400 family was commonly manufactured in a bipolar semiconductor process that operated using a +5-V power supply and was known as transistor-transistor logic (TTL). The discussion of the 7400 family thus far has included only the original +5-V bipolar type. The 7400's popularity and broad application to digital design has kept it relevant through many improvements in semiconductor process technology. As engineers learned to fabricate faster and more efficient ICs, the 7400 was redesigned in many different process generations beginning in the late 1960s. Some of the more common 7400 variants are briefly discussed here.

The original 7400 discrete TTL logic family featured typical propagation delays of 10 ns per gate and power consumption, also called *power dissipation*, of approximately 10 mW per gate. By modern standards, the 7400's speed is relatively slow, and its power dissipation is relatively high. Increasing system complexity dictates deeper logic: more gates chained together to implement more complex Boolean functions. Each added level of logic adds at least another gate's worth of propagation delay. At the same time, power consumption also becomes a problem. Ten milliwatts may not sound like a lot of power, but, when multiplied by several thousand gates, it represents a substantial design problem in terms of both supplying a large quantity of power and cooling the radiated heat from digital systems.

Two notable bipolar variants of the 7400 are the 74LS and 74F families. The 74LS, LS indicating *low-power Schottky*, has speed comparable to that of the original 7400, but it dissipates roughly 20 percent of its power. The 74F, F indicating fast, is approximately 80 percent faster than the 7400 and reduces power consumption by almost half. Whether the concern is reducing power or increasing speed, these two families are useful for applications requiring 5-V bipolar technology.

CMOS technology began to emerge in the 1980s as a popular process for fabricating digital ICs as a result of its lower power consumption as compared to bipolar. The low-power characteristics of CMOS logic stem from the fact that a FET requires essentially no current to keep it in an on or off state (unlike a BJT, which always draws some current when it is turned on). A CMOS gate, therefore, will draw current only when it switches. For this reason, the power consumption of a CMOS logic gate is extremely low in an idle, or quiescent, state and increases with the frequency at which it switches.

Several CMOS 7400 families were introduced, among them being the 74HCT and 74ACT, each of which has power consumption orders of magnitude less than bipolar equivalents at low frequencies. Earlier CMOS versions of the 7400 were not fully compatible with the bipolar devices, because of voltage threshold differences between the CMOS and bipolar processes. A typical TTL output is only guaranteed to rise above 2.5 V, depending on output loading. In contrast, a typical 5-V CMOS input requires a minimum level of around 3 V to guarantee detecting a logic 1. This inconsistency in voltage range causes a fundamental problem in which a TTL gate driving an ordinary CMOS gate cannot be guaranteed to operate in all situations. Both the 74HCT and 74ACT families possess the low-power benefits of CMOS technology and retain compatibility with bipolar ICs. A 74HCT device is somewhat slower than a 74LS equivalent, and the 74ACT is faster than a 74LS device.

There has been an explosion of 7400 variants. Most of the families introduced in the last decade are based on CMOS technology and are tailored to a broad set of applications ranging from simple speed to high-power bus drivers. Most types of 7400 devices share common pin-outs and functions, with the exception of some proprietary specialized parts that may be produced by only a single manufacturer. Most of the 7400 families still require +5-V supplies, but lower voltages such as 3.3 V, 2.5 V, 1.8 V, and 1.5 V are available as well. These lower-voltage families are important because of the general trend toward lower voltages for digital logic.

## 2.7 INTERPRETING A DIGITAL IC DATA SHEET

Semiconductor manufacturers publish data sheets for each of their products. Regardless of the specific family or device, all logic IC data sheets share common types of information. Once the basic data sheet terminology and organization is understood, it is relatively easy to figure out other data sheets even when their exact terminology changes. Data sheet structure is illustrated using the 74LS00 from Fairchild Semiconductor as an example. A page from its data sheet is shown in Fig. 2.19.

Digital IC data sheets should have at least two major sections: functional description and electrical specifications. The functional description usually contains the device pin assignment, or *pin-out*, as well as a detailed discussion of how the part logically operates. A simple IC such as the 74LS00 will have a very brief functional description, because there is not much to say about a NAND gate's operation. More complex ICs such as microprocessors can have functional descriptions that fill dozens or hundreds of pages and are broken into many chapters. Some data sheets add additional sections to present the mechanical dimensions of the package and its thermal properties. Digital IC electrical specifications are similar across most types of devices and often appear in the following four categories:

- *Absolute maximum ratings.* As the term implies, these parameters specify the absolute extremes that the IC may be subjected to without sustaining permanent damage. Manufacturers almost universally state that the IC should never be operated under these extreme conditions. These ratings are useful, because they indicate how the device may be stored and express the quality of design and manufacture of the physical chip. Manufacturers specify a storage temperature range within which the semiconductor structures will not break down. In the case of Fairchild's 74LS00, this range is –65 to 150°C. Maximum voltage levels are also specified, 7 V in the case of the 74LS00, indicating that the device may be subjected to a 7-V potential without destructing.
- *Recommended operating conditions.* These parameters specify the normal range of voltages and temperatures that the IC should be operated within such that its functionality is guaranteed to meet specifications set forth by the manufacturer. Two of the most important specifications in this section are the supply voltage (commonly labeled as either $V_{CC}$ or $V_{DD}$, depending on whether a bipolar or MOS process) and the operating temperature. An IC may have multiple supply voltage specifications, because an IC can actually operate on several different voltages simultaneously. Each supply voltage may power a different portion of the chip. When the manufacturer specifies supply voltage, it does so with a certain tolerance, usually either ±5 or ±10 percent. Many 5-V logic ICs are guaranteed to operate only at a supply voltage from 4.75 to 5.25 V (±5 percent). Operating temperature is very important, because it affects the timing of the device. As a semiconduc-