CHAPTER 1: Introduction

1.1 Background Information

Digital computers have been around since the 1940, and have been in widespread commercial use since the 1960s. Yet only in the past 10 to 20 years has the digital revolution spread to many other aspects of life. Examples of once analog systems that now have gone digital include the following:

- Audio recordings. Once made exclusively by impressing analog waveforms onto vinyl or magnetic tape, audio recordings now commonly use digital compact discs (CDs) and digital audio tape (DAT). ACD or DAT stores music as a sequence of 16-bit numbers corresponding to samples of the original analog waveform, one sample every 22 microseconds or so. A typical CD contains over 5 billion bits of information.

- Automobile carburetors. Once controlled strictly by mechanical linkages, automobile engines are controlled by embedded microprocessors. Various electronic and electromechanical sensors convert engine conditions into numbers that the microprocessor can examine to determine how to control the flow of fuel and oxygen to the engine. The microprocessor output is a time-varying sequence of numbers that operate electromechanical actuators, which, in turn, control the engine.

- Telephone system. It started out a hundred years ago with analog microphones and receivers connected to the ends of pair of copper wires. Even today most homes and businesses still use analog telephones, which transmit analog signals to the phone company’s central office (CO). However, in the majority of COs, these analog signals are converted into digital format before they are routed to their destinations, be they in the same CO or across the continent or the world.

- Traffic lights. Signal lights used to be controlled by electromechanical timers that would give the green light to each direction for a predetermined amount of time. Later, relays were used in controllers that could activate the lights according to the pattern of traffic detected by sensors embedded in the pavement. Today’s controllers use microprocessors, and can control the light in ways that maximize vehicle throughput.

- Movie effects. Miniature clay models, stop action, trick photography, and numerous overlays of film on a frame-by-frame basis were used exclusively to create special effects. Today, spaceships, creatures, other worldly scenes are synthesized using digital computers.
The electronic revolution has been going on for quite some time now and the solid state revolution began with analog devices and applications like transistors and transistor radios. The reason for this sudden spurt in digital circuit design versus analog design is due to many advantages that digital circuits offer over analog ones:

- Reproducibility of results: Given the same set of inputs, a properly designed digital circuit is consistent with its results. The outputs of analog circuit may vary with temperature, power-supply voltage, component aging and many other factors.

- Ease of design: Digital design, often called logic design, is logical. No special math skills are needed, and the behavior of small logic circuits can be visualized mentally without any special insights into the operation of capacitors, transistors, or other devices that require calculus to model.

- Flexibility and Functionality. Once a problem has been reduced to digital form, it can be resolved using a special set of logical steps in space and time. For example, you can design a digital circuit that scrambles your recorded voice so that it is absolutely indecipherable by anyone who does not have your “key”, but can be heard virtually undistorted by anyone who does.

- Programmability. Many of the computer and digital-system components themselves, called programmable logic devices (PLDs), can be programmed to perform different low-level logic functions! Furthermore, the programs in these devices can be easily modified during circuit debugging, which greatly simplifies and speeds product development.

- Speed. Today’s digital devices are fast. A typical, primitive digital logic element can examine its inputs and produce an output in less than 10 nanoseconds. This means that such an element can produce 100 million or more results per second.

- Economy. Digital circuits can provide a lot of functionality in a small space. Circuits that are used repetitively can be “integrated” into a single “chip” and mass produced at extremely attractive costs, making possible throw-away items like calculators, digital watches, and singing birthday cards.

### 1.2 Digital devices

The most basic digital devices are called gates. These devices have one or more inputs and produce an output that is a function of current input values. These input values may be analog conditions such as voltage, current, even hydraulic pressure; they are modeled as taking on just two discrete values, 0 and 1.

The three most basic gates are AND gate, OR gate and inverter. The AND gate produces an output equal to 1, only if all its inputs are 1; otherwise it produces a zero. An OR gate produces an output of 1, if at least one of its inputs is equal to 1; otherwise it
produces a zero output. An inverter on the other hand, produces an output, which is the complement of the input. A gate is called a combinational circuit because its output depends solely on its present input values.

A flip-flop is a device that stores either a zero or a 1. The state of the flip-flop is the value that it currently stores. The stored values can be stored only at certain times determined by a “clock” input, and the new value may further depend on the flip-flops current state and its “control” inputs.

A digital circuit that contains flip-flops and/or feedback lines is called a sequential circuit because the output, at any time, depends not only on its current input, but also on the past sequence of inputs that have been applied to it. In other words a sequential circuit has memory of its past events.

1.3 Various aspects of digital design.

- Electronic aspects of digital design: Digital circuits model analog voltages and currents as consisting of 1’s and 0’s. Considering a range of values to be either a digital 0 or digital 1 arrives at this model. The values that fall in between the two ranges are invalid.

- Software aspects of digital design: Computer-aided engineering software tools are important aspects of digital design. They help to improve the correctness and quality of designs. Some examples of software design are listed below:

  o Schematic Entry: This allows a digital designer to draw “on-line” schematic diagrams instead of using paper and pencil. The more advanced schematic-entry programs also check for common, easy-to-spot errors, such as shorted outputs, signals that don’t go anywhere and so on.

  o Compilers for programmable logic devices: Programmable logic devices are customized by the digital designer to perform specific (logical) functions that are required in a system design. The designer specifies the functions using “programs” in a specialized language, and the compiler produces a set of “fuse” patterns that can be programmed into the device to obtain the desired functions. Some of the languages used for this purpose are VHDL, VERILOG, PALASM, and ABEL.

  o Timing analyzers and verifiers: The time dimension is very important in digital design. All digital circuits take time to produce a new output value in response to an input change, and much of the designer’s effort is spent ensuring that such output changes occur quickly enough. Programs such as Timing Designer can automate the tedious task of drawing timing diagrams and verifying the timing relationship between different signals in a complex system.
Simulators: During debugging it’s very difficult, often impossible, to change
the gates and interconnections in a digital circuit that have been integrated into
a single chip. Usually, changes must be made in the original design database
and a new chip must be manufactured to incorporate the required changes.
Since this process takes days, even months to complete, chip designers are
highly motivated to “get it right” the first time on the very first try. Simulators
help the designers to predict the electrical and functional behavior of the chip
without actually building it, allowing most bugs to be found before the chip is
fabricated.

1.4 Integrated Circuits (ICs):

A collection of one or more gates fabricated on a single silicon chip is called
integrated circuit (IC). Large IC’s may contain millions of transistors.

IC’s can be classified by the number of gates they contain. The simplest type of
commercially available IC, is called small-scale integration (SSI), and contains the
equivalent of 1 to 10 gates. Most SSI IC’s come in a 14-pin dual in-line pin (DIP)
package, where the spacing between pins in a column is 0.1 inch and spacing between
columns is 0.3 inch. The examples for SSI IC’s are 74LS00, 74ACT00, etc. Although the
SSI IC’s are sometimes used as “glue” to tie together larger-scale elements in complex
systems, they have been largely supplanted by programmable logic devices.

The next larger commercially available IC is called medium-scale integration
(MSI), and contains the equivalent of about 10-100 gates. An MSI IC typically contains a
functional building block, such as a decoder, register, or counter.

Large-scale integration (LSI) IC’s are bigger and contain 100-100,000 gates or
more. LSI parts include memories, microprocessors, and programmable logic devices.

Very-large integration IC’s are those with over 500,000 transistors. Examples of
these IC’s include 1-Mbit and larger memories and 32-bit microprocessors.

1.4.1 Application-Specific ICs

Chips designed for a particular, limited product or application, are called semi-
custom IC’s or Application-specific IC’s (ASICs). ASICs generally reduce chip count,
physical size and power consumption and often provide higher performance.

The non-recurring engineering (NRE) cost for designing an ASIC can exceed the
cost of discrete design by $5000 to $250,000 or more. An ASIC design normally makes
sense only when the per-unit savings can amortize NRE cost over the expected sales
volume of the product.

To reduce NRE cost IC manufacturers have developed libraries of standard cells
including commonly used MSI functions such as decoders, registers, counters and
commonly used LSI functions such as memories, programmable logic arrays and microprocessors. In a standard-cell design, the logic designer interconnects the functions in much the same way as in a multi-chip MSI/LSI design. All the cells are laid out so as to reduce the propagation delay and the size of the chip. The NRE cost for a standard cell-design is of the order of $100,000.

A gate array is an IC whose internal structure is an array of gates whose interconnections are initially unspecified. The logic designer specifies the gate types and interconnections.

The main difference between standard-cell and gate-array design is that the macro-cells and chip layout of a gate array are not as highly optimized as those in a standard-cell design, so the ship maybe 25% or larger, and may cost more. On the other hand, gate-array design can be completed faster and at lower NRE cost as compared to standard cell design.

Field-programmable gate array is one of the most recent developments in ASIC technology. A field-programmable gate array (FPGA) contains programmable interconnection or fuses/anti-fuses that allow interconnection pattern to be loaded and changed (for re-programmable FPGAs) after the device is manufactured. The main advantage of FPGA is that the modifications to digital design can be made in a very little time and cost. On the other hand, FPGAs are costlier than fixed-interconnect gate array.