

Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Programmable Logic Devices



Programmable Logic Devices (PLDs)

PLDs are specialized integrated circuits (ICs) used to implement digital circuits. These circuits are programmable meaning that they can be preconfigured to create almost any design. Over the years, PLDs have grown in size and complexity and new versions have been created. They give designers a variety of options in developing digital circuits and systems.

Today, PLDs have virtually replaced most previously used types of digital logic circuits in modern electronic equipment. This module introduces the concepts of PLDs, describes the various types, and summarizes the basic approach to design, testing, and troubleshooting.

Prerequisites

The prerequisites for this module include:

- Completion of a standard course in digital logic and techniques
- Types of logic circuits and how they operate including inverters, logic gates, flip flops, decoders, multiplexers, arithmetic circuits, counters, and shift registers
- Basic introductory knowledge of microcontroller organization and operation

What Technicians Need to Know

Three main methods of implementing digital logic circuits

Concept behind programmable logic devices (PLDs)

Types of PLDs including PAL, PLA, CPLD, FPGA, and ASIC

Benefits of PLDs

Specifications, architecture, and features of each type of PLD

How PLDs are programmed

How to test and troubleshoot PLDs

Ways to Implement Digital Logic

Digital Logic Methods

Digital logic refers to those logic circuits that process binary data. The basic circuits are the AND, OR, NAND, NOR, and NOT gates, flip flops, counters, registers, and all of the combinational and sequential circuits created with these basic circuits.

The earliest digital logic circuits were made with vacuum tubes. Discrete transistors came next.

When the first digital integrated circuit (IC) logic circuits became available in the 1960s, IC logic quickly became the primary method of making computers and other digital equipment.

IC logic circuits became faster and more complex as semiconductor processing made it possible to create fully functional circuits like decoders and counters (rather than just gates and flip flops) on a single chip of silicon.

IC logic circuits led to the creation of the first microprocessors and semiconductor memories in the early 1970s.

Popular Digital Logic Circuits

The most popular digital logic circuits were the 7400 bipolar transistor-transistor logic (TTL) series of small scale and medium scale ICs. The small scale chips include inverters, gates, and flip flops. The medium scale circuits were complete functional circuits including decoders, encoders, multiplexers, counters, registers, and other special circuits.

Complementary metal oxide semiconductor (CMOS) logic circuits using enhancement mode MOSFETs were in RCA's 4000 series ICs. Later, CMOS versions of the popular 7400 series TTL also became available.

These CMOS ICs included all the basic small scale and medium scale functions of TTL.

Most computers and digital systems were made with either the bipolar TTL or CMOS ICs. Emitter coupled logic (ECL) was used in the more advanced computers.

Microprocessor Programming

The development of the microprocessor and the embedded microcontroller and programmable logic devices has virtually eliminated the use of standard digital logic circuits in building new computers and digital systems.

For low speed applications, almost any logic operation (AND, OR, counting, decoding, etc.) can be handled by programming a microprocessor. Almost all new electronic products contain at least one microcontroller that performs the necessary digital functions.

Alternatives to Simple Digital Logic ICs

While using a complete computer on a chip seems like overkill for simpler logic circuits, the very low cost and single chip nature of an embedded controller makes it practical and inexpensive as well as entirely flexible.

For large complex circuits to be used in high volume, customized logic can be used. The designer works with a semiconductor manufacturer who creates a permanent design that does exactly what is needed. The resulting device is called an application specific integrated circuit (ASIC).

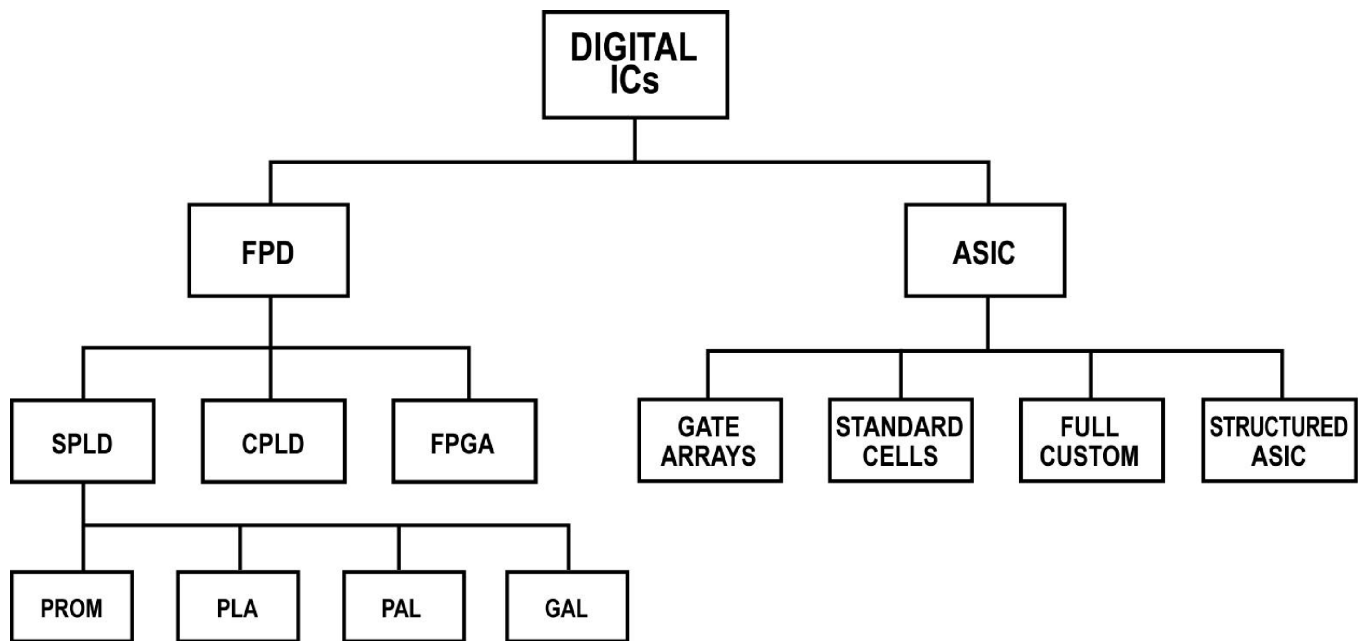
Programmable Logic

An alternative to the programmable microcontroller for high speed applications is the PLD. These devices are extremely fast and can be configured to implement any logic function or operation that was previously implemented with TTL or CMOS circuits. Even unique processors can be created for special occasions and needs.

PLDs come in a variety of forms that allow the designer to program the device using a special piece of equipment called a device programmer. Some devices can be programmed only once while others can be reprogrammed.

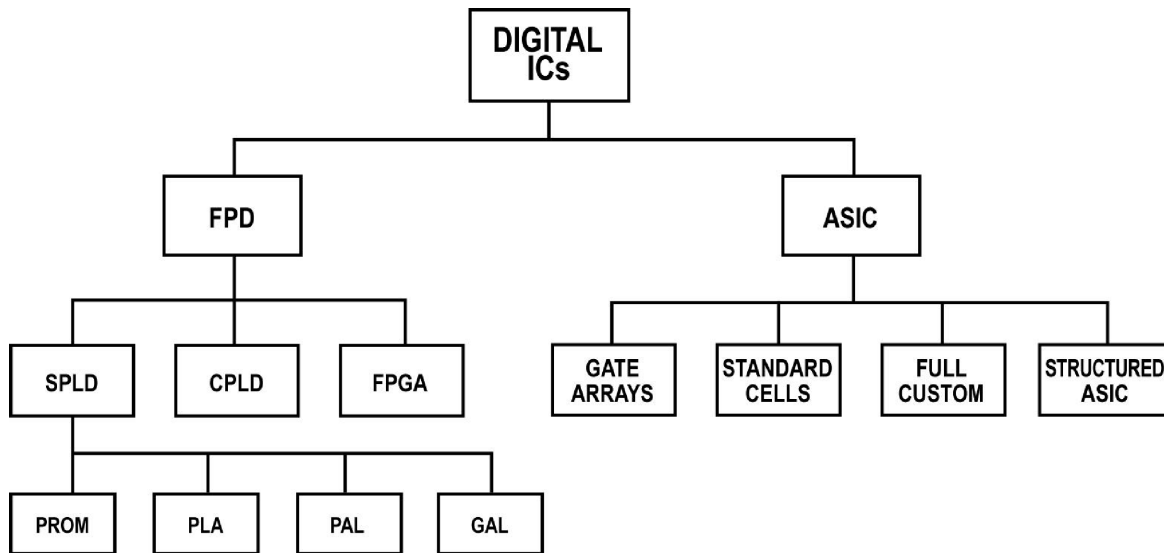
Reprogrammable devices are especially helpful to the engineer designing a circuit because the circuit can be quickly and easily changed to correct a mistake, incorporate new features and capabilities, or to improve performance. Design time and costs are greatly minimized.

Hierarchy of Logic Circuits



There are two general categories of logic circuits, field programmable devices (FPD) and application specific integrated circuits (ASICs).

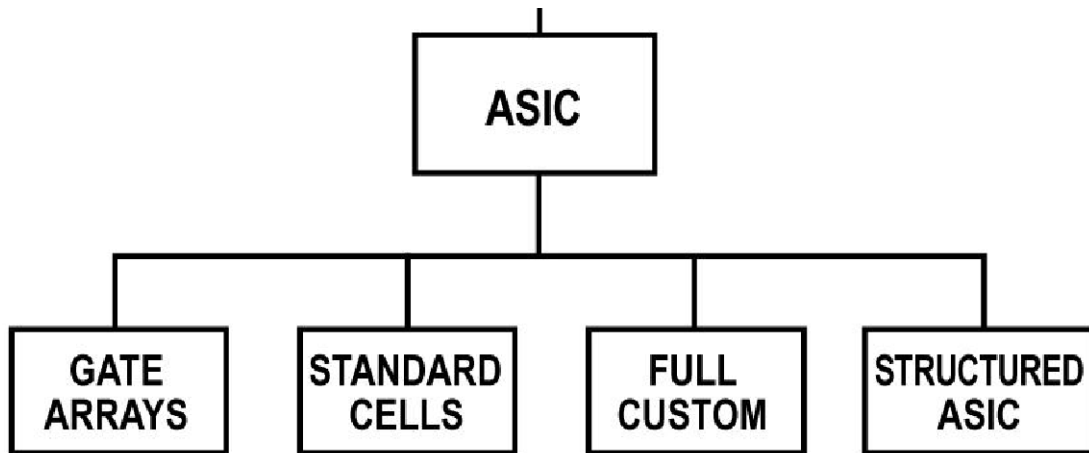
Comparison



The ASICs are typically larger and more complex than the FPDs but with the newer FPDs called field programmable gate arrays (FPGAs), the dividing line becomes fuzzy.

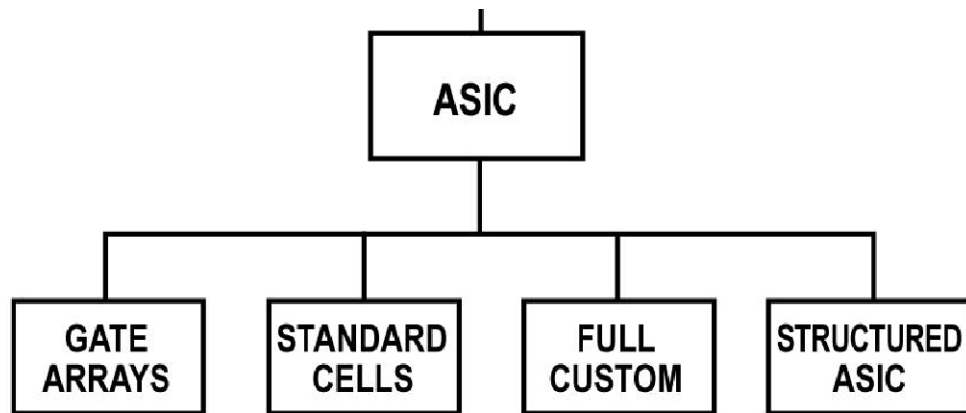
ASICs are normally used when the volume of usage of the final IC is sufficiently high (100,000+) to justify the very high design and manufacturing costs which can be spread out over many units.

ASICs



ASICs are implemented in one of four basic ways: standard cells, gate arrays, full custom circuits, and structured ASICs.

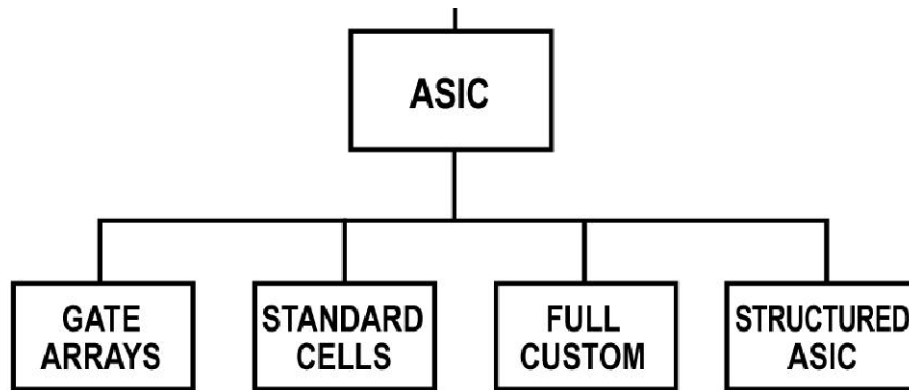
ASICs: Standard Cells and Gate Arrays



Standard cells are ICs with a large collection of logic circuits that are interconnected by creating custom wiring masks that interconnect the circuits during final manufacturing of the IC.

Gate arrays are large ICs that contain basic cells which are standard collections of components and logic circuits that may be programmed and interconnected with masks during manufacturing.

ASICs: Full Custom and Structured



Full custom logic simply means that the designer takes the final circuit to a semiconductor manufacturer who makes the IC from scratch.

A structured ASIC is a collection of logic modules that include gates and flip flops as well fully functional circuits like multiplexers, decoders, counters, registers, and other widely used circuits. These can then be interconnected by metal masks during manufacturing.

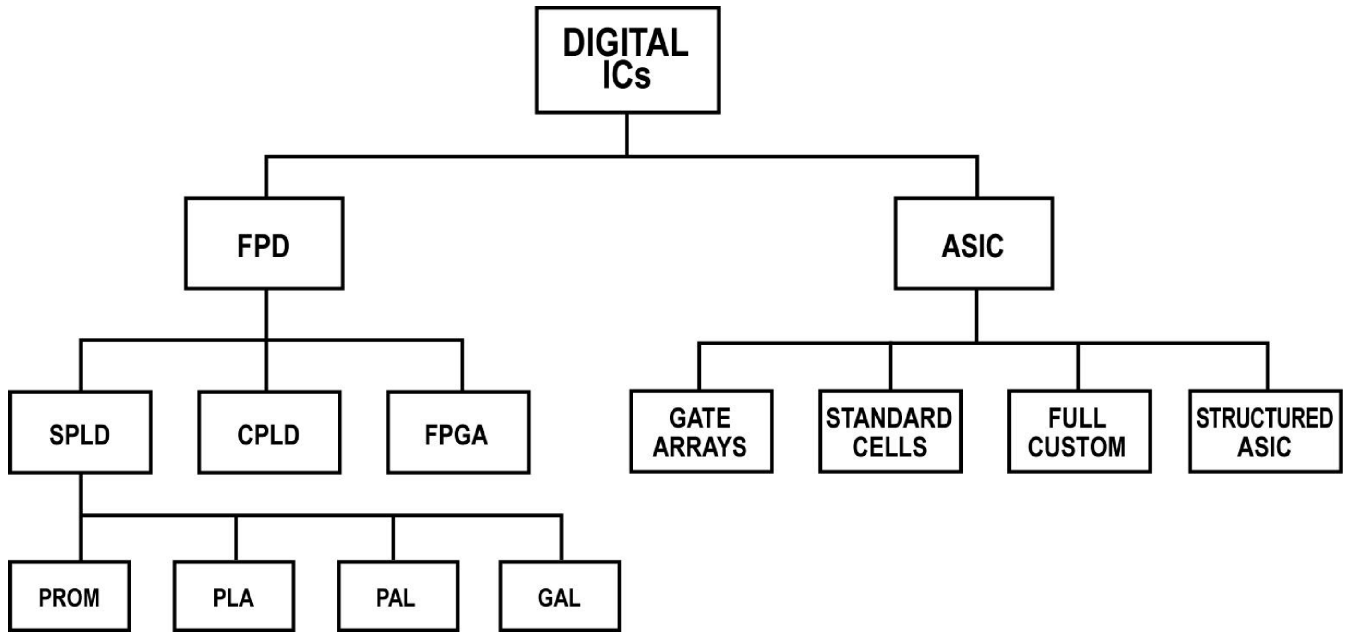
ASIC Benefits and Disadvantages

The primary advantage of an ASIC is that it is optimized for the application. Therefore, it has the best performance and functionality.

ASICs are usually very expensive because they involve custom engineering time and the expensive semiconductor manufacturer's processes. If usage volume is very high, these costs may be spread out over a large number of units thereby reducing cost.

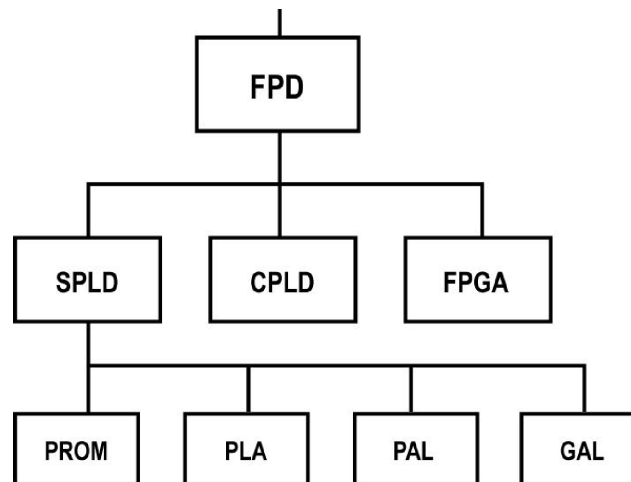
A key disadvantage is that once they are designed, ASICs may not be changed except by redesign and repeating the expensive mask change process during manufacturing. To justify an ASIC, the volume of usage must be extremely high and the performance needs must be beyond the reach of field programmable devices.

Programmable Logic Devices



The second category of logic circuit is the field programmable device (FPD). FPDs come in three basic forms: simple PLD (SPLD), complex PLD (CPLD) and field programmable gate array (FPGA).

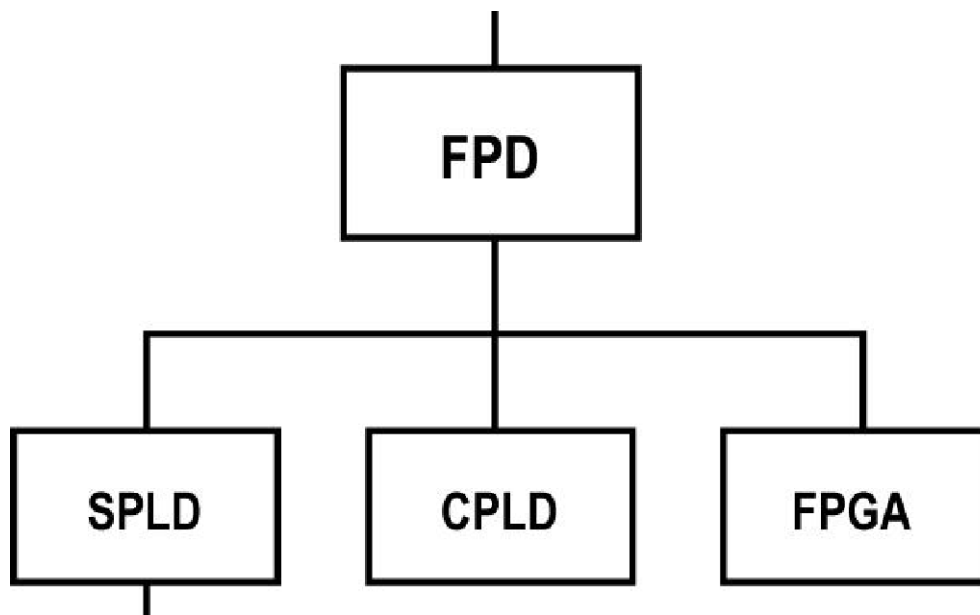
Simple Programmable Logic Devices



A simple PLD is a small scale device with AND and OR gates that can be interconnected in various ways to create the desired logic.

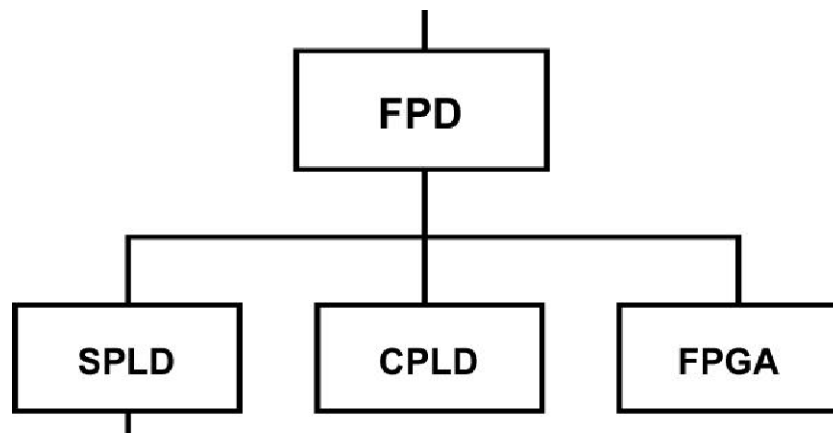
The four types of simple PLDs shown in the figure are: programmable read-only memory (PROM), programmable logic array (PLA), programmable array logic (PAL), and generic logic array (GAL). They will be discussed in the section titled “PLD Concepts and Types.”

Complex Programmable Logic Devices



A complex PLD is one that contains multiple SPLDs that can be programmed and interconnected to create larger, more complex logic functions.

Field Programmable Logic Devices



Field programmable gate arrays (FPGAs) are larger devices that contain random access memory (RAM) or PROM cells that store bit patterns that turn circuits off or on, or connect or disconnect circuits to form the desired logic.

Very large FPGAs are now challenging ASICs in many designs because their cost has decreased while speeds and number of gates have increased.

Advantages of the Alternative Methods

Most logic operations can be implemented with a single IC chip, either a microprocessor or PLD, rather than the earlier multiple chip designs.

Microcontrollers are complete computers on a chip with CPU, memory, and input/output circuits. They can be programmed to do virtually all low speed logic operations.

Embedded controllers are extremely inexpensive. They cost just a few dollars or less when produced in volume.

More Advantages

PLDs are faster than microcontrollers for most operations. They too can be programmed to do almost any operation. The result is a single IC instead of the dozens or hundreds of individual TTL or CMOS ICs previously used.

The overall cost of the logic circuitry and the overall size of the logic circuitry and printed circuit board are decreased significantly. The overall performance (speed) is improved and less power is consumed. The design process is faster and changes are easier to make.

System on a Chip (SoC)

Large ASICs and FPGAs allow a designer to put all or almost all of the circuits in a system on a single IC chip. What was once one or more large printed circuits boards (PCBs) populated with dozens or even hundreds of ICs now becomes a single IC. These ICs are often referred to as systems on a chip (SoC).

Occasionally a complete embedded microcontroller is created on the chip along with any special logic circuitry. These microcontrollers are complete CPUs with memory, input/output (I/O), and other standard features. They are typically called cores and they can be programmed as any computer or other embedded microcontroller.

Cores are often found on ASICs where they are programmed to perform some of the logic functions and the specialized logic performs the faster functions.

Test your knowledge

Programmable Logic Devices Knowledge Probe 1 Ways to Implement Digital Logic

Click on [Course Materials](#) at the top of the page.
Then choose **Knowledge Probe 1**.