

## 1: Fundamentals of Linear Electronics: Integrated and Discrete - James F. Cox - Google Books

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Analog versus digital circuits Analog , or linear, circuits typically use only a few components and are thus some of the simplest types of ICs. Generally, analog circuits are connected to devices that collect signals from the environment or send signals back to the environment. For example, a microphone converts fluctuating vocal sounds into an electrical signal of varying voltage. An analog circuit then modifies the signal in some useful way—such as amplifying it or filtering it of undesirable noise. Such a signal might then be fed back to a loudspeaker, which would reproduce the tones originally picked up by the microphone. Another typical use for an analog circuit is to control some device in response to continual changes in the environment. For example, a temperature sensor sends a varying signal to a thermostat , which can be programmed to turn an air conditioner, heater, or oven on and off once the signal has reached a certain value. A digital circuit, on the other hand, is designed to accept only voltages of specific given values. A circuit that uses only two states is known as a binary circuit. Arithmetic is also performed in the binary number system employing Boolean algebra. These basic elements are combined in the design of ICs for digital computers and associated devices to perform the desired functions. Microprocessor circuits Microprocessors are the most-complicated ICs. They are composed of billions of transistors that have been configured as thousands of individual digital circuits, each of which performs some specific logic function. A microprocessor is built entirely of these logic circuits synchronized to each other. Microprocessors typically contain the central processing unit CPU of a computer. Just like a marching band, the circuits perform their logic function only on direction by the bandmaster. The bandmaster in a microprocessor, so to speak, is called the clock. The clock is a signal that quickly alternates between two logic states. Every time the clock changes state, every logic circuit in the microprocessor does something. Calculations can be made very quickly, depending on the speed clock frequency of the microprocessor. Microprocessors contain some circuits, known as registers, that store information. Registers are predetermined memory locations. Each processor has many different types of registers. Permanent registers are used to store the preprogrammed instructions required for various operations such as addition and multiplication. Temporary registers store numbers that are to be operated on and also the result. Other examples of registers include the program counter also called the instruction pointer , which contains the address in memory of the next instruction; the stack pointer also called the stack register , which contains the address of the last instruction put into an area of memory called the stack; and the memory address register, which contains the address of where the data to be worked on is located or where the data that has been processed will be stored. Microprocessors can perform billions of operations per second on data. In addition to computers, microprocessors are common in video game systems , televisions , cameras , and automobiles. Memory circuits Microprocessors typically have to store more data than can be held in a few registers. This additional information is relocated to special memory circuits. Memory is composed of dense arrays of parallel circuits that use their voltage states to store information. Memory also stores the temporary sequence of instructions, or program, for the microprocessor. Manufacturers continually strive to reduce the size of memory circuits—to increase capability without increasing space. In addition, smaller components typically use less power, operate more efficiently, and cost less to manufacture. Digital signal processors A signal is an analog waveform—anything in the environment that can be captured electronically. A digital signal is an analog waveform that has been converted into a series of binary numbers for quick manipulation. As the name implies, a digital signal processor DSP processes signals digitally, as patterns of 1s and 0s. The digital representation of the voice can then be modified by a DSP using complex mathematical formulas. For example, the DSP algorithm in the circuit may be configured to recognize gaps between spoken words as background noise and digitally remove ambient noise from the waveform. DSPs are also used to produce digital effects on live television. For example, the yellow marker lines displayed during the football game are not really on the field; a DSP adds the lines after the cameras shoot the picture but before it is broadcast.

Similarly, some of the advertisements seen on stadium fences and billboards during televised sporting events are not really there. As their name implies, ASICs are not reconfigurable; they perform only one specific function. For example, a speed controller IC for a remote control car is hard-wired to do one job and could never become a microprocessor. An ASIC does not contain any ability to follow alternate instructions. RFICs are analog circuits that usually run in the frequency range of 3 kHz to 2. They are usually thought of as ASICs even though some may be configurable for several similar applications. Most semiconductor circuits that operate above MHz million hertz cause the electronic components and their connecting paths to interfere with each other in unusual ways. Engineers must use special design techniques to deal with the physics of high-frequency microelectronic interactions. These circuits usually run in the 2- to GHz range, or microwave frequencies, and are used in radar systems, in satellite communications, and as power amplifiers for cellular telephones. Just as sound travels faster through water than through air, electron velocity is different through each type of semiconductor material. Silicon offers too much resistance for microwave-frequency circuits, and so the compound gallium arsenide GaAs is often used for MMICs. Unfortunately, GaAs is mechanically much less sound than silicon. It breaks easily, so GaAs wafers are usually much more expensive to build than silicon wafers. Basic semiconductor design Any material can be classified as one of three types: A conductor such as copper or salt water can easily conduct electricity because it has an abundance of free electrons. An insulator such as ceramic or dry air conducts electricity very poorly because it has few or no free electrons. A semiconductor such as silicon or gallium arsenide is somewhere between a conductor and an insulator. It is capable of conducting some electricity, but not much. Doping silicon Most ICs are made of silicon, which is abundant in ordinary beach sand. Pure crystalline silicon, as with other semiconducting materials, has a very high resistance to electrical current at normal room temperature. However, with the addition of certain impurities, known as dopants, the silicon can be made to conduct usable currents. In particular, the doped silicon can be used as a switch, turning current off and on as desired. The process of introducing impurities is known as doping or implantation. An n-type semiconductor results from implanting dopant atoms that have more electrons in their outer bonding shell than silicon. The resulting semiconductor crystal contains excess, or free, electrons that are available for conducting current. A p-type semiconductor results from implanting dopant atoms that have fewer electrons in their outer shell than silicon. In essence, such holes can move through the crystal conducting positive charges. Three bond pictures of a semiconductor. The p-n junction A p-type or an n-type semiconductor is not very useful on its own. However, joining these opposite materials creates what is called a p-n junction. A p-n junction forms a barrier to conduction between the materials. Although the electrons in the n-type material are attracted to the holes in the p-type material, the electrons are not normally energetic enough to overcome the intervening barrier. However, if additional energy is provided to the electrons in the n-type material, they will be capable of crossing the barrier into the p-type material and current will flow. This additional energy can be supplied by applying a positive voltage to the p-type material. The negatively charged electrons will then be highly attracted to the positive voltage across the junction. The p-n junction A barrier forms along the boundary between p-type and n-type semiconductors that is known as a p-n junction. Because electrons under ordinary conditions will flow in only one direction through such barriers, p-n junctions form the basis for creating electronic rectifiers and switches. A forward-biased p-n junction Adding a small primary voltage such that the electron source negative terminal is attached to the n-type semiconductor surface and the drain positive terminal is attached to the p-type semiconductor surface results in a small continuous current. This arrangement is referred to as being forward-biased. A p-n junction that conducts electricity when energy is added to the n material is called forward-biased because the electrons move forward into the holes. If voltage is applied in the opposite direction a positive voltage connected to the n side of the junction no current will flow. The electrons in the n material will still be attracted to the positive voltage, but the voltage will now be on the same side of the barrier as the electrons. In this state a junction is said to be reverse-biased. Since p-n junctions conduct electricity in only one direction, they are a type of diode. Diodes are essential building blocks of semiconductor switches. Field-effect transistors Bringing a negative voltage close to the centre of a long strip of n-type material will repel nearby electrons in the material and thus form holes that is, transform some of

the strip in the middle to p-type material. This change in polarity using an electric field gives the field-effect transistor its name. While the voltage is being applied, there will exist two p-n junctions along the strip, from n to p and then from p back to n. One of the two junctions will always be reverse-biased. Since reverse-biased junctions cannot conduct, current cannot flow through the strip. The field effect can be used to create a switch transistor to turn current off and on, simply by applying and removing a small voltage nearby in order to create or destroy reverse-biased diodes in the material. A transistor created by using the field effect is called a field-effect transistor FET. The location where the voltage is applied is known as a gate. The gate is separated from the transistor strip by a thin layer of insulation to prevent it from short-circuiting the flow of electrons through the semiconductor from an input source electrode to an output drain electrode. Similarly, a switch can be made by placing a positive gate voltage near a strip of p-type material. A positive voltage attracts electrons and thus forms a region of n within a strip of p. This again creates two p-n junctions, or diodes. As before, one of the diodes will always be reverse-biased and will stop current from flowing.

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