The Integrated Circuit Hobbyist's Handbook

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Foreword

For those who became interested in electronics after integrated circuits became widespread, it is difficult to imagine how hobby electronics once was. Try locating some issues of a magazine like *Popular Electronics* published in the 1950s or early 1960s. Circuits in those magazines—such as timers, pulse generators, audio amplifiers, or logic gates—required numerous discrete components like transistors (or vacuum tubes!), resistors, and capacitors. A lot of soldering and debugging was necessary to get the circuit to work right. Today, ICs performing those functions are available for less than a dollar. All the hard work has been done—all you have to do is plug the IC into a solderless breadboard, add a few external components, and in a couple of minutes you have a functioning circuit equivalent to that requiring hours of work in the 1950s or 1960s. And since it's easy to make changes to the circuit (you don't have to de-solder components), you much more likely to actually experiment with a circuit instead of just duplicate one in a magazine. No matter what anyone tries to tell you, the "good old days" of electronic experimentation weren't all that good!

But there are areas where experimenters actually had it easier a quarter century ago. Back in the early days of semiconductors, big electronics companies like Motorola and RCA actively sought business from electronics hobbyists. Such companies sold transistors and the earliest ICs directly to hobbyists in single-unit quantities, like Motorola's "HEP" (hobby/experimenter program) line of semiconductors. In addition, they published numerous manuals and reference sources for hobbyists; anyone could get a copy of the data sheet for a transistor just by dropping a note to the manufacturer. There were also numerous books published for electronics hobbyists that contained information on how to use components and working applications circuits. Today, however, most semiconductor companies ignore electronics hobbyists. The special manuals just for hobbyists are just a memory, and most companies will send a data sheet for an IC only if requested on company or professional letterhead. Companies do make information about their devices available in large compilations known as "data books," but these are normally available only to professional engineers or for a fee. An electronics hobbyist could easily spend several hundreds of dollars for a complete set of data books from major electronics companies!

This book is an effort to provide IC experimenters and hobbyists with a reference to basic IC theory, applications, and a selection of popular devices. This is far from a comprehensive reference to all ICs now available, but instead concentrates on those devices most commonly used by hobbyists as well as certain specialized linear devices (such as fluid detector ICs) available to hobbyists which can be the foundation for several interesting projects.. The information given for each device includes a brief description, pin connections, basic operating parameters and specifications, logic tables (if applicable), and applications circuits. Since this book is aimed at experimenters and hobbyists rather than professional engineers, a "cookbook" approach has been emphasized. However, professional engineers will probably find it quicker to locate information about common devices in this book than by looking through fat data books!

If you haven't yet started experimenting with integrated circuits, this book is a good place to start as basic theory about integrated circuits in general and major types of ICs has been included. All of the circuits in this book are battery powered, so there's no danger of electrocution. The circuits can be built on a solderless breadboard, so now special construction skills are needed. And the price of ICs continues to drop—some of the devices in this book are available in the United States for only a few cents. If you're interested in ICs, don't delay any longer. Try experimenting with the devices in this book today!

CHAPTER ONE

Experimenting with ICs

There is some dispute over who should get credit for inventing the integrated circuit. Most observers credit Jack Kilby of Texas Instruments. In the summer of 1958, Kilby was a new employee who had not accumulated enough service to qualify for a vacation during the company's scheduled summer vacation period. With most of his co-workers gone, Kilby had enough free time to devote to his attempt to fabricate a complete working circuit—a phase shift oscillator—onto a single slice of germanium. By September, Kilby had completed a functioning prototype and Texas Instruments filed for a patent in 1959. Shortly after Kilby began his work, Robert Noyce of Fairchild Semiconductor started working on a different process for fabricating complete circuits on a single piece of semiconductor material, and he also filed for a patent in 1959. Maybe the fairest statement is to say that Jack Kilby was the first to make an actual working integrated circuit, while Bob Noyce was the one who made it practical to manufacture ICs in commercial quantities. By 1961, Texas Instruments was selling ICs to its customers. By the mid-1960s, Motorola made available the first ICs that electronics hobbyists could afford. Within a decade, ICs totally dominated the hobbyist and commercial markets, leaving transistors restricted to such specialized applications as radio frequency oscillators and amplifiers.

When the first ICs came on the scene, they were considered technical marvels because they contained the equivalent of two or three transistors, plus supporting components like capacitors and resistors, on a single chip of semiconductor material. A measure of the progress made in ICs is that today there are ICs which contain the equivalent of over one million transistors on a single chip!

Inside an Integrated Circuit

Many manufacturer data sheets for simple integrated circuits contain what is known as an "equivalent circuit," which is a schematic diagram of the circuit function contained in the IC if you tried to build it using discrete components. If you ever examine a data sheet with an equivalent circuit diagram, you would see transistors, diodes, capacitors, and resistors used. There would probably be no inductors, however, since it is not yet possible to integrate most values of inductance onto a slice of semiconductor material. (IC designers use some interesting techniques to avoid using inductors or to simulate inductive effects.) While early ICs were made from germanium, the overwhelming majority of ICs today are fabricated on silicon.

Just like discrete semiconductors, ICs are fabricated using P-type and N-type semiconductor material. Transistors and diodes are made from the junctions of those two types of material. Most bipolar transistors found on an IC are NPN type. IC transistors can also be metal oxide semiconductor (MOS), field effect transistor (FET), or MOSFET. Resistors are formed from small sections of P-type material while capacitors are formed by reverse-biasing PN junctions.

The foundation for an IC is a wafer of P-type semiconductor material known as a *substrate*. Numerous ICs (over 100 in some cases) can be fabricated on a single wafer, with the wafer cut apart afterwards to make the individual chips. Most ICs are still manufactured using the *planar* process which Noyce developed in 1959. In the planar process, the various integrated components extend below the surface of the substrate. Figure 1-1 shows a cross-section of a substrate containing a transistor and a resistor.

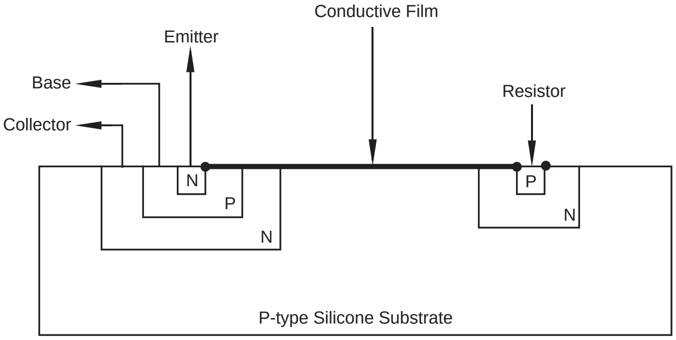

Figure 1-1

The circuit to be integrated is first designed and laid out on a scale hundreds or, increasingly common, thousands of times larger than the actual chip. The pattern of the circuit is then photographically reduced to the wafer size to form a *mask*. The substrate is coated with a thin layer of silicon dioxide or other insulating material, and additional thin layers of P-type and N-type material are placed atop the layer through a process known as *epitaxy*. The wafer is then treated with a photosensitive coating known as *photoresist*, and the mask is placed on the wafer. The wafer/mask combination is exposed to ultraviolet light, causing the photoresist to etch the circuit pattern into the substrate. The circuit elements are "completed" by diffusing or implanting various amounts of impurities into the substrate. The various circuit elements are electrically isolated from each other, however. Interconnection of the elements is made by applying a conductive film to the etched wafer. As the film evaporates, it leaves behind a conductive residue in the etched circuit connection patterns on the wafer.

ICs are often described as being "monolithic" or "hybrid." A monolithic IC is a complete functioning circuit on a single chip, while a hybrid IC is formed from two or more chips connected together to form the final working circuit.

Integrated Circuit Packaging

Once separated from the wafer, all ICs are enclosed in a protective packaging. The most common type of packaging is a rectangular black plastic or ceramic case with matching rows of pins along the two long sides of the case. This is called the *dual in-line package* (DIP). Figure 1-2 shows a typical DIP.

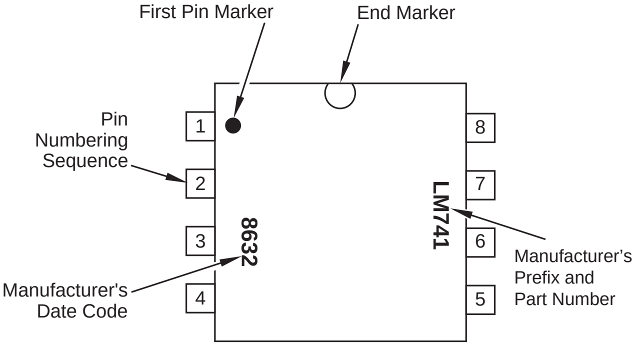

Figure 1-2

DIP ICs are marked in ways to help you identify the device and it pins. One end of the IC will have a semicircular notch or indentation. This indicates which end of the IC will be considered "up." The pin in the uppermost left corner from this notch is pin 1 of the IC. Pin numbering proceeds "down" from the left side of the IC and then continues with the uppermost pin to the right of the notch. Some ICs will have a dot or other marker adjacent to pin 1, but not always.

Usually the largest lettering on the IC will be for the device's part number, and this will usually be preceded by the manufacturer's prefix. Table 1-1 gives a list of the most common prefixes. Some of these will quickly become second nature to you and you'll automatically think "Motorola" when you see MC or "Texas Instruments" when you see "SN." For very popular ICs made by different manufacturers, it's common to just use part numbers alone, as in "741" or "7400." Such devices from different manufacturers are functionally identical to each other, and that practice will be followed in this book.

Table 1-1

COMMON IC MANUFACTURER PREFIXES

Prefix	*Manufacturer*
AD	Analog Devices
Am	Advanced Microdevices
CA, CD	RCA (now part of Harris)
DM	National Semiconductor
H	Harris
HA	Hitachi
I	Intel
ICL, ICM	Intersil
IDT	Integrated Device Technology
L, LD	Siliconix
LF, LH, LM	National Semiconductor
LT	Linear Technology
MC, MM	Motorola
N, NE	Signetics
PM	Precision Monolithics
SE	Signetics
SN	Texas Instruments
SP	Plessey
TL	Texas Instruments
WD	Western Digital
XR	Exar
µA	Fairchild Semiconductor (now part of National Semiconductor)

Some manufacturers include date codes on ICs to indicate when they were produced. These usually consist of the last two digits of the year plus two additional digits. The two additional digits could represent the week or month the IC was manufactured, depending on the company. A code like "9324" could indicate the IC was made during week 24 of 1993. These date codes have no meaning for you as a hobbyists; these are used by manufacturers to determine if particular production runs have an abnormally high percentage of defects or other problems.

Another IC packaging you may see is a small metal "can" that looks like an oversize discrete transistor with multiple leads. Most ICs in this packaging will have 8, 10, or 12 leads and an identifying tab on one side. This tab usually indicates the *last* pin number; the first pin immediately to the left of the tab is pin 1 of the IC. Pin numbers run counterclockwise until the last number is reached. Figure 1-3 shows the usual pin arrangement for this packaging.

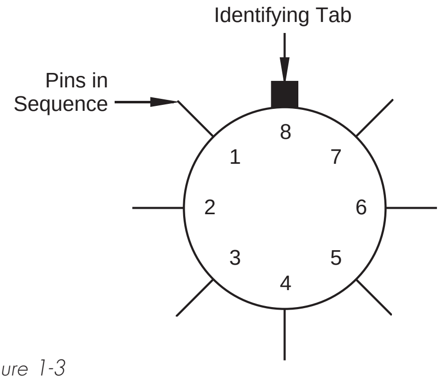

Figure 1-3

A type of IC packaging not widely used by hobbyists is the *surface mount* package. Surface mount packages resemble a smaller version of DIPs, with flat "pins" on the sides. Unlike DIPs, surface mount packages are not designed to be inserted into circuit boards or solderless breadboards. Instead, they lay atop the circuit board and are soldered to it. Surface mount ICs were designed for use in automated assembly operations, and are often supplied in "reels," much like a reel of movie film, from which the IC s can be unloaded by the automatic assembly equipment for placement on the circuit boards. Because of their small size, surface mount ICs are difficult to manually place and solder.

Throughout this book, we will assume that DIP ICs are being used and all pin identification diagrams will be based on the DIP packaging. This is because ICs in DIP housing are the most common and easiest to use with solderless breadboards. Most the application circuit diagrams in this book will include pin numbers of the IC being used. To build the circuit illustrated, just add the part or make the connection to the IC at the pin number specified. You will also see parts of some of circuit diagrams labeled with a $^1/_2$ or $^1/_4$, as in "$^1/_2$ 1458." This means that the IC has two or more identical circuits, such as two op amps, four NAND gates, etc. The 1458 is an IC containing two equivalent op amps, either of which can be used for a circuit function. The diagrams in this book will normally indicate the pin numbers for only circuit, but any of the other devices could be used with the same results. However, in some cases the wiring connections will be easier (that is, components won't get in the way of other components) if you follow the pin numbering we give.

Building IC Circuits

The best method of experimenting with ICs is to use a “breadboard” to build circuits. Breadboards (more formally known as *solderless modular sockets*) get their name from the early days of radio, when it was common to build vacuum tube circuit prototypes on a wooden breadboard. Today’s breadboards are a grid of insulating plastic atop a pattern of conducting metal strips. Figure 1-4 shows the top of a breadboard. Component leads and wires are inserted into the holes and make contact with the conducting metal strips underneath, thus “connecting” them together.

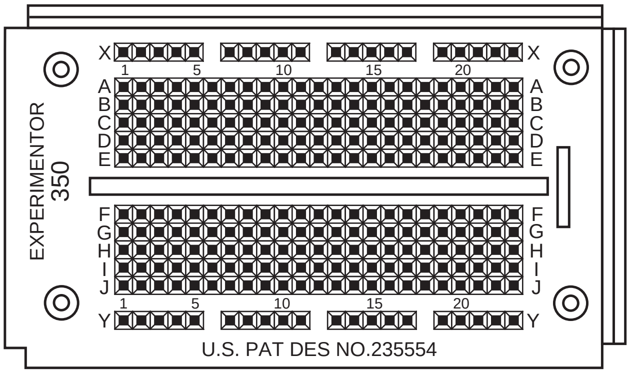

Figure 1-4

Figure 1-5 gives a better understanding of how breadboard works. This figure shows the pattern of conducting strips underneath the solderless breadboard shown in Figure 1-4. Notice there are two vertical strips along the sides of the breadboard and a series of shorter horizontal strips between the two vertical strips. The two vertical strips are normally used for the power supply connections, with one strip being the supply voltage and the other the ground connection (breadboard with four vertical strips are available and are used for circuits requiring a dual polarity power supply). These vertical strips are often referred to as *rails*. You’ll notice there is a gap between the horizontal strips, and the DIP IC package is normally placed across this gap. One row of pins is on one side of this gap, and the other row of pins is on the opposite side.

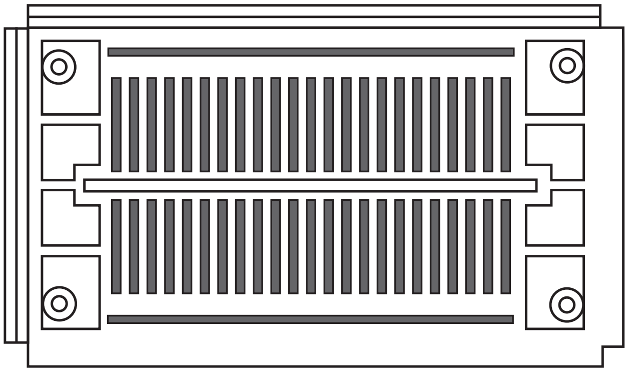

Figure 1-5

Breadboards come in a variety of sizes, and are usually measured in terms of the number of connection or “tie points” provided. Some breadboards come with binding posts for connecting a power supply; deluxe models even come with power supplies built in (typically for +5 and/or +9 volts) together with supports for additional components such as potentiometers, LEDs, and meters.

While breadboards are terrific for experimenting with ICs, they are not suitable for more permanent versions of circuit designs. Parts and connecting wires can easily be knocked out of the breadboard’s connecting holes, so something sturdier is required. One method for permanent circuit construction is to use *perfboard*. Perfboard is a section of phenolic board through which numerous small holes have been drilled. Parts leads are inserted through the holes and are either twisted together or connected by “jumper” wires before soldering. All connections and soldering are normally done on one side of the perfboard. Soldering to ICs can present a problem, however, since the pins are small and ICs can be easily damaged by excessive heat. A solution is to use IC sockets. All soldering is done to the socket, and the IC is inserted into the socket after the solder cools.

A technique that avoids soldering and lets parts be easily re-used is *wire wrapping*. A wire wrap circuit card is covered with IC sockets having short pins protruding from the underside of the wire wrap card. ICs can be inserted directly into the sockets while discrete components are first mounted on adapters that plug into the sockets. The various components are connected by conducting wires wrapped around the pins attached to each socket connection. The wires are attached to each pin by a wire wrapping tool, which comes in manual and automatic types. The reliability and strength of a wire wrapped connection is often equal to that of a soldered connection but with much less chance of damaging an IC than if soldering is used. Changes can easily be made to the final circuit and parts may be re-used.

Power Supplies

The power supply requirements are given with the specifications of each device in this book. As a general rule, however, +5 volts has become the standard supply voltage for TTL and CMOS digital logic ICs. This is because all TTL ICs require a fixed, stable +5 volt power source and most CMOS devices can operate anywhere from +3 to +18 volts. There are numerous commercially available power supplies which can deliver +5 volts. Another way to obtain this voltage is to "drop" the voltage from a 6 volt source (like four 1.5 volt cells connected in series). Figure 1-6 shows a simple circuit to do this. The +5 volt output goes to one rail of a breadboard while the ground connection goes to the other. Pay particular attention to the polarity of the capacitors when building the circuit (see the note at the end of this section).

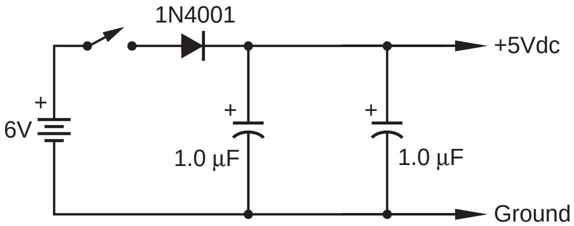

Figure 1-6

Power supply requirements for linear devices are more complex. Most linear devices can operate over a wide voltage range, but some cannot operate properly at +5 volts. The closest thing to a standard linear device operating voltage is +9 volts. This can be provided by a standard 9 volt battery; a good +9 volt power supply design is given in Figure 5-1 of Chapter 5. If a dual polarity voltage source is needed, a circuit like the one in Figure 1-7 can be used.

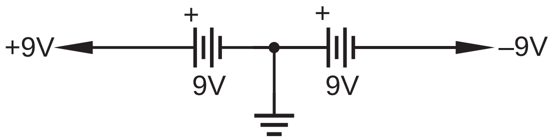

Figure 1-7

Perhaps the easiest way to obtain the necessary supply voltages for your IC circuits is to use a commercial power supply with multiple output voltages. These have a fixed +5 volt output and one or more variable output voltages with switchable polarities.

A Special Notice about Capacitor Polarities

Many circuits in this book use *polarized* capacitors. The most commonly used polarized capacitors will be the *electrolytic* type. You can identify circuits using polarized capacitors by the polarity symbols (+ and -) adjacent to the capacitor schematic symbol. The term "polarized" means the capacitor must be connected in a certain way with respect to the supply voltage polarities. If it is not connected correctly, a polarized capacitor will be destroyed. At higher voltages (in excess of 9 volts) and large values of capacitance, the capacitor can actually explode like a small firecracker!

The key rule to remember is always: *the positive side of a polarized capacitor must always be connected to a positive voltage source.* Polarized capacitors will be marked on their can with a + symbol next to the lead for the positive side of the capacitor. In addition, the longer of the two leads on a polarized capacitor will be the positive side. Take your time when building a circuit using polarized capacitors and make sure the polarity is correct. Even veteran IC experimenters blow a polarized capacitor when they get in too big of a hurry!

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