SAMS

Don Lancaster

TTL Cookbook

- TTL applications and projects
- Complete catalog of integrated circuits
- TTL circuit design tips and techniques

TTL Cookbook

By

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Preface

I don't like to revise books. Correct, yes. Revise, no. So I won't.

A book becomes history the instant it appears in print. To tamper with history messes with what others and I were thinking at the time and distorts the way things were, forcing new contexts.

With the *TTL Cookbook,* it is now January 1982, and this book is eight years old. It is also one of the best selling technical paperback classics of all time. And looking around, both nothing has changed and everything has changed.

TTL is still the largest and most popular general purpose logic family, although it now shares the spotlight with an only somewhat smaller and very aggressive CMOS logic family. Most all TTL in use today is the Low Power Schottky or the "74LS" variety. The latest version of this is now called "ALS" for *Advanced Low Power Schottky,* with speed and power advantages. At this writing ALS is new enough that it has not replaced LS yet, but it is only a matter of time.

Surprisingly few new devices have been added to the original TTL list. We now have a handful of new "octal" or eight-wide registers, counters, latches, and bus drivers. These usually come in slightly longer 18, 20, 22 or rarely 24 pin narrow packages. Mercifully, a few of the older TTL device with really atrocious pinouts have been rearranged for sane PC layout. Most notable of these is the 74LS244 bidirectional bus driver, which now has a "straight thru" layout and is called the 74LS640.

The TTL bipolar Programmable Read Only Memory, or PROM, isn't used nearly as much as it was. Smaller 32 × 8 devices have been discontinued by some manufacturers, while others have sharply raised prices. Larger sizes remain available. The reason for the decline is a NMOS family of EPROMs that includes the 2716, 2732, and 2764. Besides being erasable, reusable, denser, and much easier to program, NMOS family EPROMS are now also super cheap. They seem to have run away with almost all the marbles.

Bipolar PROMS using TTL technology do still have one advantage. They are still ten times faster than the 2716, with a typical access time of 50 nanoseconds, compared to the 500 or so of a 2716. So, you might still use bipolar ROMS if speed is essential.

The *Programmable Logic Array,* or PLA, has recently taken off. A wide variety of reasonably priced devices are available, from *Monolithic Memories, National,* and others. These combine gates and registers in a you-program-it array that meets your custom logic needs.

Advantages are far fewer packages and simplified stocking. These PLA's have largely replaced data selector logic designs.

Another thing that hasn't changed is that a thorough understanding of TTL remains central to understanding and using just about everything new and modern in electronics. TTL is very much mainstream and will stay that way for a very long time.

What has changed explosively, though—in case you have been asleep for the last five years—is the microprocessor revolution. Very simply and very bluntly, if it is electronic and doesn't have a microprocessor in it, it is not worth doing. And that applies to ALL electronics, radio, radar, television, communications, power control, hi-fi, video disks and recorders, appliances, cameras, pagers, satellite receivers, data acquisition, process controls. Everything electronic. You name it.

Very few people are dumb enough to still go out and design an electronic something by taking a bushel basket of TTL or other general purpose logic family and then hand-wiring everything together. Today you do everything you can with changeable software, making any remaining hardware very general and flexible.

What does this do to TTL?

Almost all microprocessor systems need some TTL as "glue" to hold them together. Many of the exciting new peripheral add-ons for micros extensively use TTL. These new microprocessor support applications are so exciting and so widespread that they are now the dominant use of TTL chips.

While micros have dramatically increased the use of TTL and made an understanding of TTL even more essential than before, they have also very much narrowed the focus of what is important in TTL and what gets used how. Today, we use TTL bus drivers, registers, latches and low level logic gates extensively with micros. We have to thoroughly understand latches and D-flops, and the logic of handshaking communications between micros and the outside world. We also see new and special TTL devices to handle such things as dynamic refresh and memory management.

But we no longer worry too much about how to build a divide-by-37 counter, since this is better done with software. We no longer would build a TTL clock, digital voltmeter, or frequency counter, except as a student exercise, since you can get ready-to-go chips that do the entire job for you. And building your own TTL central processing unit for a computer, when you can buy an entire microprocessor for $3, is lunacy. Unless, of course, you are the military or into extreme speed.

When I wrote the *TTL Cookbook,* I purposely changed some of the pin callouts on some devices to clarify their use to an absolute beginner. For instance, "1", "2", "4", and "8" was used instead of "A", "B", "C", and "D", "OUT" was used for "Y", and so on. Enables were called enables, even if they were really a strobe or a chip select, and so on. Some uses of some pins were also simplified. On the whole, this has eliminated a lot more confusion than it created, and I am still glad I did it, and no, I won't change things. Same goes double for my not using negative logic symbols.

Taken together, the *TTL Cookbook,* and its companion *CMOS Cookbook* (SAMS 21398) remain essential for your understanding both the hardware background and the technical fundamentals driving the microprocessor revolution.

Rather than add new devices to these books, watch for a new volume in the works called *Don Lancaster's Micro Cookbook, Volume III,* which shows you devices from all the important logic and support families, similar to chapter two of the TTL cookbook.

Don Lancaster
January, 1982

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Other SAMS books by Don include *Active Filter Cookbook, CMOS Cookbook, Cheap Video Cookbook, Son of Cheap Video, TV Typewriter Cookbook, The Hexadecimal Chronicles, Don Lancaster's Micro Cookbook,* and *The Incredible Secret Money Machine.*

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CHAPTER 1

Some Basics of TTL

A *digital logic family* consists of a group of integrated circuits or other elemental, compatible blocks that can be combined in various ways to perform a series of "yes-no" decisions based on the presence or absence of "yeses" and "nos" on various inputs, and possibly taking into account the history of previous "yeses" and "nos" gone before.

Depending on how you interconnect these logic blocks, you can build a computer, a calculator, an electronic music system, a digital voltmeter or counter, a television terminal readout display, a color-tv dot-bar generator, educational demonstrators, or any of thousands of other possibilities. While a single "yes-no" decision by itself usually is not too useful, the proper combination of grouped "yes-no" decisions taken together can represent a number, a word, a command, a musical note, a test signal, or practically anything else you might like.

One digital-logic family that is extremely popular today is called *Transistor-Transistor-Logic,* otherwise known as TTL, T^2L, or "Tee Squared Ell." Important advantages of TTL are its low cost (as low as 30¢ per package in single quantities on the surplus market), its high-speed capability (20 MHz typical; to 125 MHz with special devices), its moderate drive capability and noise immunity, and the industry-wide availability of hundreds of different devices. This gives you a broad selection of simple and elaborate logic blocks that may be directly interconnected to produce more unique functions with fewer packages than virtually any other present logic system.

TTL started out as many device lines by many manufacturers. Today, the bulk of the available and useful devices are in a 5400–7400 numbering system, originally pioneered by Texas Instruments, but now an industry standard. The 7400 line is lower in cost and is useful over a 0- to 70-degree C environment. The 5400 line is a premium military line good from −55 to +125 degrees C. There are a few important non-7400 TTL devices, particularly in the Motorola MC4000 MTTL, the Signetics 8200, and National Tri-State® product lines. Some of these devices offer unique advantages and are widely second-sourced, but even these are beginning to pick up 7400-type number equivalents as they become more of an industry standard, (on page 39).

There is a tendency to assume that most integrated-circuit logic families are pretty much the same, particularly if they work on the same +5-volt supply. This simply is not so, and each logic family has some unique characteristics and use restrictions that are all its own. In the case of TTL, the first-time user is often surprised that the outputs of his circuits never seem to get much more than halfway up to the +5-volt supply, and that unconnected inputs pull themselves up to a positive value. Further, he finds it is very difficult to get the inputs down to ground where they belong for a "low" input condition, unless whatever is pulling them down can *sink* a reasonable amount of current. It turns out there are very good reasons for these design quirks of TTL; most of these peculiarities are necessary for reliable, high-speed operation. Let us take a closer look at a typical TTL device and see what the basic input-output characteristics are.

THE TWO-INPUT, POSITIVE-LOGIC NAND GATE

Fig. 1-1 shows the internal schematic of one-quarter of a 7400 NAND gate. This is one of the most versatile building blocks in the TTL line. In fact, you could build almost any TTL circuit with nothing but this

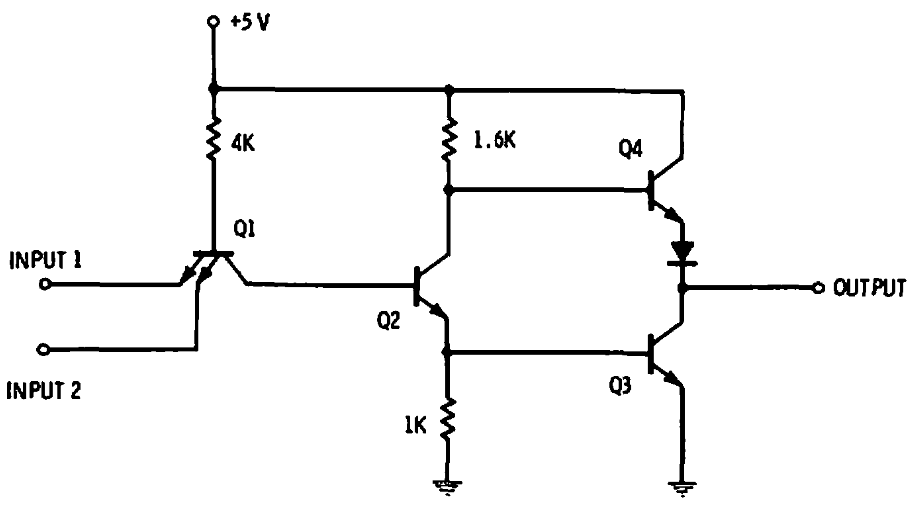


Fig. 1-1. Two-input positive NAND gate.

particular device if you had enough of them and did not mind all the extra packages. We will shortly see that this is an elemental logic block whose output is positive if either input is grounded, and whose output is grounded only if both inputs are positive.

Suppose that neither input is connected. There is no current out of either emitter of our dual-emitter input transistor, so it does not behave as a transistor. Instead, the base-collector junction is forward biased, and a current flows from the +5-volt supply through the junction diode and into the base of Q2. Q2 will turn on. This also turns on Q3. It robs Q4 of base current, so it simultaneously turns Q4 off. The output goes to within a few tenths of a volt of ground, and we say the output state is *low*. Note that in this condition, the output is capable of absorbing or sinking to ground considerable outside-world current. This is why TTL is called *current-sinking* logic.

If we connect both inputs to a voltage that is more positive than the voltage drop across a few diodes (2.4 volts to be exact), transistor Q1 still does not behave as a transistor, since the emitter-base junction remains reverse biased. While we should never leave a TTL input unconnected because of noise problems, there is no difference between an unconnected input and an input connected to a voltage greater than 2.4 volts but equal to or less than the +5-volt supply.

With both inputs positive or at a positive logic 1, the output of the gate goes to ground. What happens if we ground one input? Q1 now behaves as a transistor, and it turns on, pulling its collector near ground. This turns Q2 off, which then turns off Q3. With Q2 off, the current now can flow through the base junction of Q4. Q4 is now free to turn on. The output swings positive. Note that the output cannot reach the positive supply, for there has to be some voltage drop across the 1.6K resistor, and we get a 0.6-volt drop across the base-emitter junction of Q4 and a second 0.6-volt drop across the output diode. The output typically will only go positive by 3.3 volts or so on a +5-volt supply.

When either input is grounded, the output is forced positive. What if both inputs are grounded? The same thing happens, so the operating circuit rules for the 7400 are as stated in Chart 1-3.

We will find in Chapter 3 that this logical operation is called a positive-logic NAND or a negative-logic NOR function.

When an input is grounded, about 1.6 milliamperes of current has to flow through the grounding lead. If we attempt to ground the input through a resistance, there will be a voltage drop across this resistance,

CHART 1-3. Logic Rules for the NAND Gate

Either or both inputs grounded	Output POSITIVE
Both inputs positive	Output GROUNDED

and the emitter will not be pulled close enough to ground to let the gate operate reliably. The maximum permissible low-state input voltage is around 0.8 volt. At any input above that, the gate will either lose noise immunity or stay in its active region and possibly oscillate. Thus, any resistive connection to ground should be less than 500 ohms (with the regular 7400 TTL family), and any input-low connection must place and hold the input below 0.8 volt positive.

These input and output conditions may seem strange when compared to older logic families. There is one big benefit. When two TTL circuits are cascaded, they "look" at each other transistor-to-transistor. There are no coupling resistances or stored charges to contend with, and the logic family thus turns out to be extremely fast in operation.

A CLOSER LOOK

Circuits in the TTL logic family may be directly interconnected—the output of one to the input of one or more other packages. The drive capability of a digital logic IC is called its *fan-out*. Its input needs needs are called its *fan-in*. The voltage and current conditions needed for a medium-power TTL gate usually are normalized to a fan-in of one unit load. The average TTL gate can drive ten unit loads, and thus has a fan-out of ten. The typical TTL input has a fan-in of one, and all newer TTL devices are designed to have a unity fan-in. Logic blocks with higher fan-outs are usually called *buffers;* these typically have a fan-out of 30. Another type of logic block may be called a decoder-driver or simply a driver. Here the outputs are converted to a group of currents or voltages compatible with some outside-world device, such as a 7-segment readout or a Nixie® tube, and "fan-out" as such has no meaning as these outputs do not drive additional TTLs.

If you exceed the fan-out of a gate, the noise margin first becomes impaired, and then the voltage and current swings become too small to operate all the attached loads reliably. Fortunately, it is only rarely that you have to interconnect more than ten inputs to a single TTL output.

There are usually only two steady-state output conditions on a TTL gate. The *output-low* state is within a few tenths of a volt of ground and is called a positive logic 0. It is capable of sinking considerable current, usually 16 milliamperes. The *output-high* state is usually called a positive logic 1. When it is connected to other TTL circuits, all it has to do is hold the emitters of the various inputs reverse biased. It need only provide for leakage currents. The output-high state is above 2.4 volts and well below the positive supply; 3.3 volts is typical.

Remember that a TTL output-positive logic 0 pulls to ground and sinks a lot of current; a TTL output-positive logic 1 simply provides a positive voltage a little over half the supply voltage.

If we ever want the full power-supply voltage as an output, we can use the circuit of Fig. 1-2, where we add a 2.2K pull-up resistor. This is never needed in a TTL-only circuit, but is handy if we are interfacing some other logic family or want the full supply swing for outside-world circuits. Without the resistor, a positive logic 1 is about 3.3 volts with a +5-volt supply.

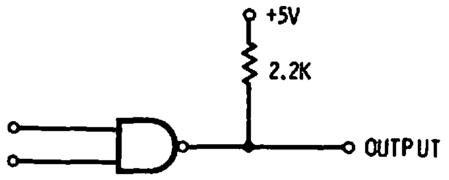


Fig. 1-2. A pull-up resistor may be added to a TTL gate if the full supply-voltage swing is wanted as an output.

Another unique feature of TTL that almost always causes trouble if it is not understood is the way in which the output switches. In the output-low state, only the bottom one of the *totem-pole* pair of transistors conducts. In the output-high state, only the top transistor in the totem-pole output conducts.

During the transition from low to high or vice-versa, both transistors conduct heavily. The instantaneous current is perhaps ten times the normal supply current. This speeds up the switching time of the output stage nicely, but at the same time, it pulls a large *current spike* out of the power-supply lines. This spike could be a fraction of an ampere or more and typically lasts 10 nanoseconds.

Unless a good bypass capacitor is provided immediately beside the IC, this current spike can raise havoc with other ICs in the system! This is an inherent feature of TTL and is one of the key sources of its speed. We will be looking at some bypassing rules soon when we talk about power supplies. Another inherent feature of the current spiking and high-speed potential taken together is that TTL can and usually will behave erratically in "rats nest" breadboarding or in traditional "perf-board" construction unless extreme care is taken with layout and conductor shapes and sizes.

The TTL output swing is from a few tenths of a volt of ground with a large current-sinking capability up to a positive voltage somewhere above half the supply voltage that needs only hold subsequent inputs positive and provide a very small leakage current.

The TTL input swing is also two-state. In the low condition, we have to sink 1.6 milliamperes to ground, and regardless of how we do it, we have to guarantee that the emitter voltage is 0.8 volt or less. In the high condition, all we have to do is hold the input positive above 2.4 volts and provide a very low leakage current. An unattended, unconnected TTL input will pull itself high to the positive logic 1 condition, but will be susceptible to noise and ringing. Good practice calls for an unused input to be tied to +5 volts or tied to a logically similar input. (The military practice of tying to +5 volts via a 1K resistor is usually not justified by the benefits and causes more problems than it solves.) As a practical matter, TTL inputs can usually be floated in a breadboard circuit if there is no lead connected to the package pin, but in final circuit versions, all inputs must be properly terminated.

A few TTL output structures differ from the totem-pole type we have just discussed. One version is called an *open collector* system. A second is called the *Tri-State®* logic system. These are in the minority and are covered in more detail in Chapter 3.

There are also some protective diodes placed on the inputs to all newer TTL gates. When these are added, the actual 7400 schematic looks like Fig. 1-3. Most TTL gates have input clamping diodes as

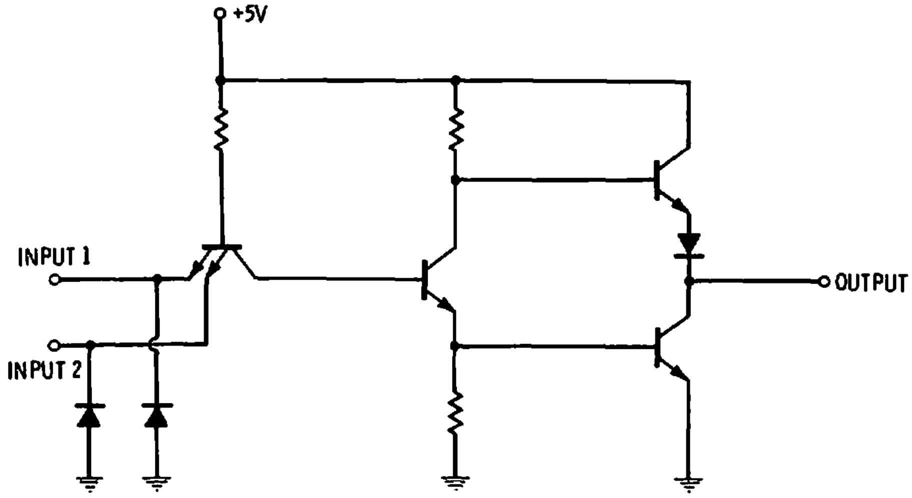


Fig. 1-3. Protective diodes connected to input gates.

shown. The purpose of these diodes is to prevent high-frequency ringing, particularly when longer leads or sharp rise inputs are applied. They improve the high-frequency noise immunity considerably. By the same token, they and the rest of the IC can be immediately destroyed if an input is brought below ground by more than 0.6 volt from a low-impedance source. This can be a problem in interface circuits. Preferably, the inputs should never be allowed to go below ground. If they must be below ground in your particular circuit, be sure to limit the reverse bias current to 10 mA or less with external series resistance. Avoid reverse biasing, if at all possible.

OTHER LOGIC BLOCKS

While the two-input NAND gate is an extremely versatile logic block, there are hundreds of others available. A one-input gate is called an *inverter* or a *noninverting buffer* or *driver,* depending on whether the output follows or complements the input. In complementary circuits, the output will be a zero when the input is a one and vice versa. Other two-input gates are available that perform different logic on the two inputs. These include the AND, OR, NOR, NAND, and EXCLUSIVE OR gates and are detailed in Chapter 3. We can have more than two logic inputs, with three-, four-, and eight-input NAND gates being common.

Gate-only circuits usually operate immediately and without regard to the history of the ones and zeros fed to the device. If history is important, we get into memory and counting devices, such as *JK Flip-Flops, D Flip-Flops, Latches,* and so on. Gates and the simple flip-flops are usually called SSI, short for *small-scale integration.*

One step beyond SSI is MSI or *medium-scale integration.* Here gates and flip-flops are suitably interconnected to produce system blocks that are called shift registers, counters, adders, decoders, data selectors, distributors, and memories. When an MSI device is aimed at one specific special-purpose task, it will have some functional name instead, such as a parity generator, a rate multiplier, a priority encoder, or a decoder-driver. The majority of TTL devices are MSI.

LSI stands for *large-scale integration* and is usually reserved for entire systems on a chip. The only common TTL LSI chip is the 74181 Arithmetic Logic Unit, used for central calculations in a computer or calculator.

In Chapter 2, we will take a closer look at the more popular TTL devices and see what they do and how to use them. One of the big benefits today in TTL is the incredible variety of MSI devices available.

PACKAGES

Some TTL is available in Mil-spec ceramic flat packages. These are expensive and very hard to use. The majority of devices are available in the common 14- and 16-pin DIP or dual in-line package, where plastic and more expensive ceramic versions are common. A very few TTL devices have too many input pins for the 16-pin package; these are reserved for the larger 24-pin DIP.

The pin conventions of the three common packages are shown in Fig. 1-4. The supply connections usually, but not always, go on diagonally opposite pins. On a 14-pin package, pin 7 is ground and 14 is +5 volts. On a 16-pin package, pin 8 is ground, and 16 is +5 volts. Pin 12 is ground and pin 24 is +5 volts on the 24-pin package. There are just enough exceptions to these supply rules, particularly with early devices, that you should double check each device before wiring it.

Usually, more than one logic block goes into a package. For instance, a quad 2-input gate contains four separate 2-input gates in a single package. A dual 4-input gate holds two separate 4-input gates in the same package. Except for the supply and ground connections, the individual blocks are completely independent. They may be used

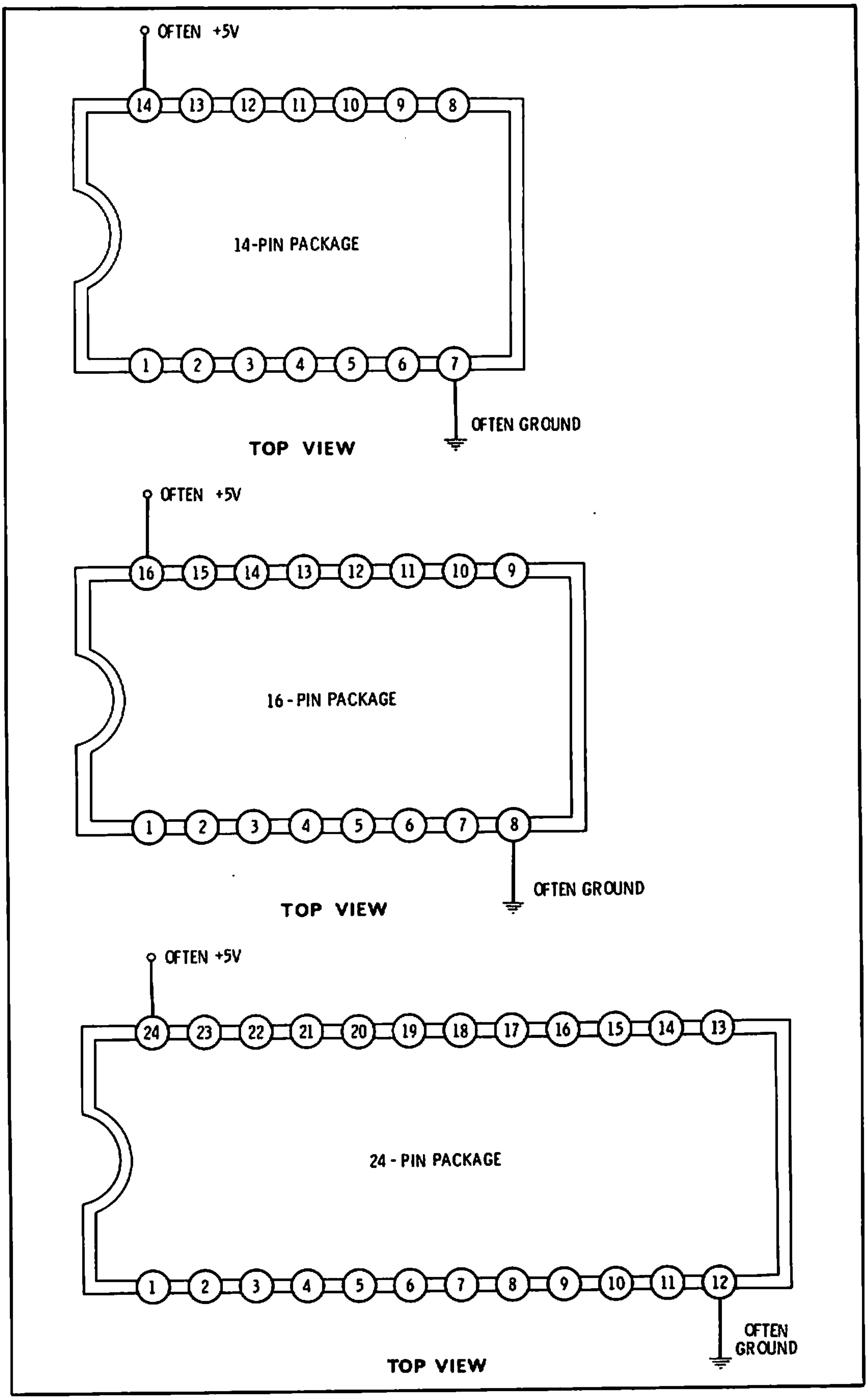


Fig. 1-4. TTL package numbering.

together or in totally separate circuits. Other common examples are hex inverters with six 1-input gates per package, and dual counting flip-flops, which contain two individual bistable logic blocks that can count and shift as well as remember data.

TYPES OF TTL AVAILABLE

There are several different *subfamilies* of TTL that trade off speed, power, and additional complexity for special uses. The TTL we have talked about so far is usually known as *regular* TTL. The other subfamilies are called *Low-Power* TTL, *High-Power* TTL, *Schottky* TTL, and *Low-Power Schottky* TTL. Table 1-1 compares the typical characteristics of each subfamily, while Table 1-2 shows the usual part-numbering system to identify a family of a given temperature range. Finally, Table 1-3 is a rough "rule of thumb" for the tradeoffs you can expect in terms of speed and power as you change subfamilies.

Table 1-1. Typical Characteristics of TTL Subfamilies

Family	Gate Propagation Time	Power per Gate	Maximum Counter Frequency
Regular TTL	10 nanoseconds	10 milliwatts	35 megahertz
High-Power TTL	6 nanoseconds	22 milliwatts	50 megahertz
Low-Power TTL	33 nanoseconds	1 milliwatt	3 megahertz
Schottky TTL	3 nanoseconds	19 milliwatts	125 megahertz
Low-Power Schottky TTL	10 nanoseconds	2 milliwatts	45 megahertz

Table 1-2. TTL Subfamily Numbering

Family	−55° to +125° C	0° to +70° C
Regular	5400	7400
High-Power	54H00	74H00
Low-Power	54L00	74L00
Schottky	54S00	74S00
Low-Power Schottky	54LS00	74LS00

Regular TTL

Regular TTL is normally the widest available and the lowest-priced type of TTL, and it has far and away the greatest variety and second-sourcing. A typical gate-propagation time is 10 nanoseconds; this is the time it takes for a logic change at a gate input to appear as a logic change on the output. Around 10 milliwatts per gate is needed, and counting flip-flops go as high as 35 MHz.

Such devices as the Motorola MC4016 and MC4018 and the Signetics 8280 and 8288 counters were originally "non-7400" devices. They now have 7400 equivalents and are *essentially* identical to regular 7400 TTL. They may have a slightly different fan-in requirement and the output positive-voltage swing may be slightly different, but the

Table 1-3. A Comparison of TTL Subfamilies

Family	Speed	Power
Regular	X1	X1
High-Power	X2	X2
Low-Power	X1/10	X1/10
Schottky	X3.5	X2
Low-Power Schottky	X1	X1/5

devices can usually be freely mixed with traditional 7400 devices. Fan-out is normally ten regular TTL devices.

Low-Power TTL

Low-power TTL exchanges power consumption for speed and is identified by an *L* in the part number. For instance, a 74L00 is a low-power, commercial version of the 7400 regular TTL NAND gate. There is roughly a 10:1 tradeoff in the low-power version—$\frac{1}{10}$ the speed to counters at $\frac{1}{10}$ the power, although the simpler gates run $\frac{1}{4}$ the speed on $\frac{1}{10}$ the power. Flip-flops and counters have a maximum toggle frequency of 3 MHz or so. Within the low-power subfamily, the fan-out remains ten, but a low-power TTL gate can drive only one regular TTL gate. While the 54L00 and 74L00 series TTL do offer low-power consumption, many of their advantages are being pre-empted by the CMOS logic families, particularly the RCA 4000 series COSMOS and the Motorola MC14000 series McMOS lines.

High-Power TTL

The high-power TTL devices are designated with an *H* in the part number. 74H00 is the equivalent of a 7400 gate, and so on. Typically you get twice the speed for twice the power. Counters are good to 50 MHz. Within the high-power subfamily, the fan-out remains at 10, but the fan-in is typically 1.3 times regular TTL loads. Thus, a regular TTL gate can drive at most only 7 high-power TTL inputs. High-power TTL is largely being replaced by the newer Schottky TTL which is faster and draws less supply power. Quite a few high-power devices remain available. One advantage they do have over the Schottky devices is that the outputs are "quieter," a handy feature in high-speed digital-to-analog converters, but hardly useful elsewhere.

Schottky TTL

Schottky TTL is an improved version of TTL that has a better speed/power tradeoff than the older types. To do this, Schottky diodes (a fast diode with a 0.3-volt forward drop) are placed across most of the transistors in the basic TTL gate. This prevents the transistors from saturating and thus eliminates any storage-time delays inside the transistors. The part numbers have an *S* in them, as in a 74S00. Propagation delays of 3 nanoseconds are combined with flip-flops that can run at 125 MHz.

Where high speed is essential, Schottky TTL is a logical choice. Its competitor is MECL and other emitter-coupled logic families which in general are much faster, but considerably more difficult to use.

A high-speed, unsaturated logic family such as Schottky TTL presents serious restrictions in the type and quality of test equipment you must have to work with it intelligently. A 60-MHz triggered oscilloscope is essential and a 120-MHz one is preferable. As might be expected, Schottky devices are much more critical as to layouts and supply decoupling than ordinary TTL because of their higher speed. Nevertheless, where high speed is essential, they are often the simplest solution to system problems in the 30- to 120-MHz range.

Low-Power Schottky TTL

Devices such as the 74LS00 are emerging as a more recent variation on TTL. The low-power Schottky TTL family is slightly faster than regular TTL, but requires only ⅕ the power. It does this by using the Schottky diodes to eliminate storage-time effects, but then raises the circuit impedance levels to slow things down to normal and pick up power savings. For many applications, this represents a near-optimum combination of values. Being newer and inherently more complex than regular TTL, the LS series is higher priced. As of this writing, it also does not have as extensive a variety of devices or suppliers as the regular 5400/7400 series TTL does.

Which Family?

While all these variations of TTL are available as design options, the regular-power traditional TTL remains the cheapest and usually the widest available choice. Very often, it is also the best overall design choice. 74S is essentially replacing 74H, and 74L is being challenged by CMOS. 74LS will represent a good choice when it is cost competitive with regular TTL and has enough different devices readily available.

The best rule today seems to be to choose regular TTL unless you have a specific speed problem, and then choose 74S. Remember that for all but the simplest high-speed systems, you will need a highperformance oscilloscope and high-quality circuit layouts to intelligently use the faster subfamily. If ultra-low-power operation is essential, particularly at low clocking frequencies, consider using CMOS as an alternate to the low-power TTL subfamily.

POWER SUPPLIES AND SPIKE DECOUPLING

Good power-supply design is essential with TTL. When choosing a power-supply design, there are three important considerations: assurance of a regulated supply of voltage, provision for a low-impedance supply distribution system, and effectiveness in decoupling the current spikes that happen every time a totem-pole output stage changes state in either direction.

TTL needs a single 5-volt positive supply. It should be regulated within 250 millivolts of this value, particularly if there are many ICs in the system. While some simple gate circuits can be run with batteries or wider-range unregulated supplies, a solid, tightly regulated supply is almost essential for any circuit that is more complex. You can use batteries with TTL if you place a regulator between the battery and the circuit. Allowing for the drop across the regulator, this means a supply in the 7.5- to 12-volt range.

At the TTL package, the absolute limit recommended for supply on most devices is 7 volts. There are some specific TTL devices whose output lines can withstand 15, 30, and even 60 volts, but even these packages must have their supply pins tightly held at 5 volts.

Power-Supply Circuits

Fig. 1-5 shows a 5-volt, 750-milliampere, regulated, line-operated supply, while Fig. 1-6 shows a battery and regulator circuit. In both

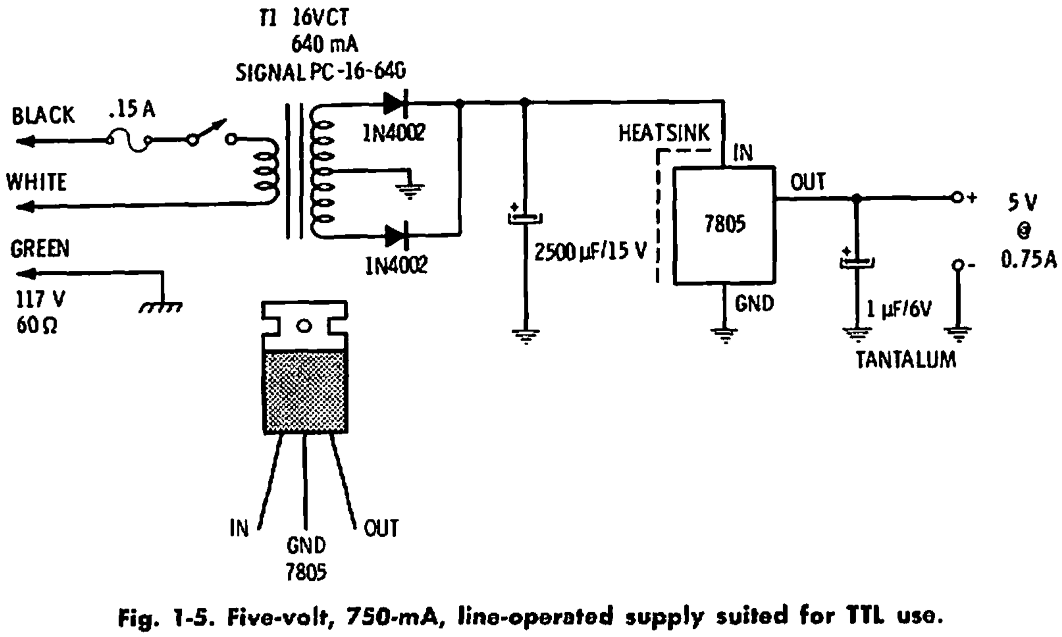


Fig. 1-5. Five-volt, 750-mA, line-operated supply suited for TTL use.

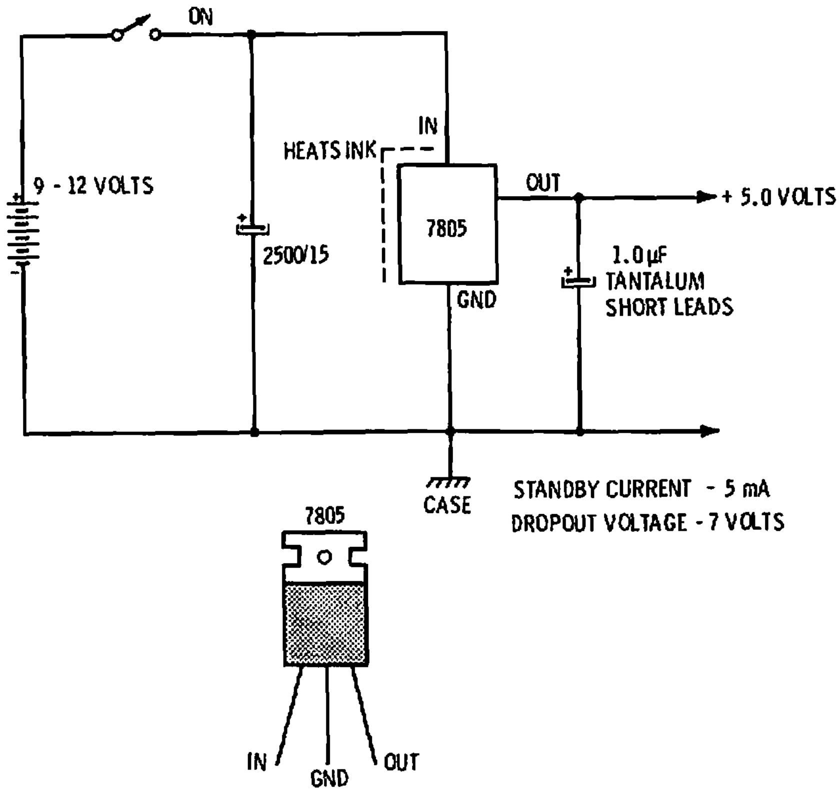


Fig. 1-6. Battery-powered TTL supply. Maximum current depends on battery chosen.

circuits, a type 7805 regulator (Fairchild, Motorola, etc.) gives a single-package, low-cost (around $2) way of precisely sensing and holding the output at 5 volts. The dropout voltage of the regulator is about 2.5 volts, so a minimum input supply of 7.5 volts must be used. If you need more than 100 mA in your circuit, the regulator should have a heatsink, either to a free-standing vertical unit intended for this regulator (IERC, Wakefield, etc.) or mounted to the case or chassis. The regulator is automatically current limiting at 750 mA and protects itself and the rest of the power supply from short-circuit damage.

The 1-μF electrolytic shown on the output must be a high-quality tantalum capacitor and must be very near the regulator as it greatly aids the stability and transient response of the sensing electronics inside the 7805.

If you need more power, fixed 5-volt regulators good to several amperes are available from several sources, including National Semiconductor, or pass transistors may be added to lower-power regulator circuits, following the manufacturer's recommendations on a data sheet or application note.

Any other power supply that can deliver the right amount of current and hold its output in the 4.75-volt and 5.25-volt range from no load to full load can be used as well.

At 5 volts, there is no shock hazard to personnel, but as you get into heavier current supplies for large systems, the supplies start looking more and more like an arc-welding circuit. Screwdrivers have been burned in half in more than one instance, so, even with current limiting, use extreme care not to short a high-current supply.

How Much Current?

There is only one accurate way to calculate supply-current needs. This is to check the data sheet for each and every component in the system and add up the totals. There is usually a difference in power consumption on a gate whose inputs are all 1's from one whose inputs are all 0's, and this should be allowed for if the circuits are predominately in one state.

TTL power needs are essentially independent of frequency, except for very high speeds where additional current must be allowed for. A TTL MSI counter that changes only twice a day to show the AM/PM position of a clock needs about the same operating current as a device running at 100 kHz.

Usually two power values are given on the data sheet. Typical values may be used rather than maximum, provided the power supply has at least an extra 25 to 50% capacity.

A quick, but much less accurate, way to calculate the supply power is to use the estimates of Chart 1-4, which has some average currents for more-or-less typical regular-power TTL. For instance, if your system has 3 counters, 2 shift registers, a dual flip-flop, 2 gates, a hex inverter, and 6 pull-up resistors, you will need around 350 mA. A supply that can handle 450 to 500 milliamperes would be recommended, and the circuit of Fig. 1-5 would be ideal.

Another way to estimate supply power is on a package dissipation basis. Very simple TTL circuits need 75 milliwatts per package. Circuits of medium complexity need about 125 milliwatts, and very large ones need about 250 milliwatts. By dividing the total milliwatts by 5, you will get the current in milliamperes. Once again, enough supply reserve should be provided to allow for worst-case operation and possible circuit expansion.

Chart 1-4. Estimating Regular TTL Currents

Each simple gate package	8 mA
Each hex inverter	12 mA
Each more complex gate	18 mA
Each dual flip-flop	25 mA
Each MSI block	60 mA
Each 2.2K pull-up resistor	3 mA

Final values should be multiplied by at least 50% and preferably should be doubled.

Supply Leads

The interconnections between supply and circuit have to be low impedance at all frequencies below 50 MHz with regular TTL, and at all frequencies below 150 MHz with Schottky TTL. Sudden changes or high-speed operation in one TTL circuit must not be subject to carry-over into other circuit areas via the supply lines. Low impedance means low inductance. This is most easily achieved by short lengths and wide, thin conductors. Low impedance means that several different values of capacitors have to be used in parallel. While a 50,000-μF electrolytic might be an excellent ripple filter on a power supply, its power factor and self-resonant frequency allow it to provide little or no high-frequency bypassing. In fact, at high frequencies, an electrolytic usually looks like a large inductor. Thus a 50,000-μF electrolytic needs a 1-μF tantalum, a 0.01-μF disc, and possibly a 500-pF mica capacitor in parallel with it, with the smaller capacitors placed as near as possible to the potential sources of high-frequency noise. It is not the total capacitance, it is how the capacitance is distributed throughout the circuit that determines how quiet the supply lines will be.

The supply runs themselves should have the lowest possible impedance. Wide foil runs on pc boards are essential, with a ground at least 5⁄16″ wide recommended as the main ground distribution run on a pc board, and 1⁄4″ the minimum width for a master supply run. When power leaves a pc board, it should go by way of heavy terminals or through several connector pins in parallel. If the regulator circuit allows it, each board should have additional electrolytics in addition to high-frequency bypassing. Runs outside the pc board should be very heavy leads of minimum length. Flat bonding-strap material or the removed outer shield of a large shielded cable is ideal, but No. 14 or No. 16 wire may be used in smaller systems.

When several pc boards with TTL are used, it is usually better to put one smaller regulator on each board rather than to have one huge regulator at the main power supply. How much time and effort you spend on supply distribution depends on the size of the system and how far it is from the farthest IC back to the power supply. The best overall rule is to use a distribution scheme that is somewhat more than you think you will need—*and then make it heavier!* Glitches and erratic operation traced to supply problems are very hard to find, so extra effort at the beginning can eliminate a lot of headaches.

How you treat ground-return leads is equally important. Ideally, there should be only one common ground-return point for your entire system, and the location should be preferably at the point where the regulator is sensing the output voltage. In larger systems, more exotic ways of transmitting information from pc board to pc board may be needed. These include such things as *line drivers* and *receivers*—or *optical couplers* may be used to isolate both signal and ground. The rule in any system is to give the TTL a chance to operate properly. Good practice calls for buffering or gating reset lines before they leave a pc board and not running input ground-return signals through the same lead that is carrying the master current back to the supply.

One effective solution to power-supply distribution is to use miniature laminated-buss distribution systems. You can purchase these or build your own out of tape and flat metal. The object is to place wide, flat conductors close together, but insulated from each other, and use one for supply and one for ground. This minimizes and distributes the inductance and provides lots of distributed bypassing capacitance at the same time. Another benefit of the busses is that they often can reduce a multilayer pc board to a double-sided one, or a double-sided one to a single-sided one.

Despiking Capacitors

TTL is not only sensitive to supply- and ground-line noise, but it also generates a lot of its own noise when any totem-pole output structure changes state and draws a heavy current spike from the supply lines. These narrow spikes must be kept from going through the supply system, ringing the lines, and upsetting other stages. Local capacitors have to be used to momentarily provide the energy for the supply during the output transitions. These are called *despiking capacitors.* Small disc capacitors in the 0.1- to 0.01-μF range, 10 volts or higher, with the shortest possible lead lengths are recommended. Other capacitor types will self-resonate on their own lead lengths and look inductive at the frequencies where they are needed most.

Here is a list of rules for capacitor placement. But the cardinal rule is this: Use enough for your needs—*and then add some more!*

Use one 0.01- to 0.1-μF short-leaded disc capacitor for every four gate packages.

Use one 0.01- to 0.1-μF short-leaded disc capacitor for every two MSI packages.

Use a separate 0.01- to 0.1-μF short-leaded disc capacitor for every package separated more than three inches from the nearest bypass capacitor.

Use a 10-μF 6-volt tantalum electrolytic where the +5-V line leaves any printed-circuit board.

Enough despiking capacitors properly placed are absolutely essential for proper TTL operation. Note that a 1-μF capacitor at the supply is *not* equivalent to 20 capacitors of 0.05 μF each, properly spread through the system. This is, first, because the capacitors are not in parallel—they are separated by the inductance and transmission time of the interconnecting leads. Second, the larger single capacitor has a much lower resonant frequency for a given lead length and style of capacitor, so it is more likely to behave as an inductive reactance at frequencies of interest.

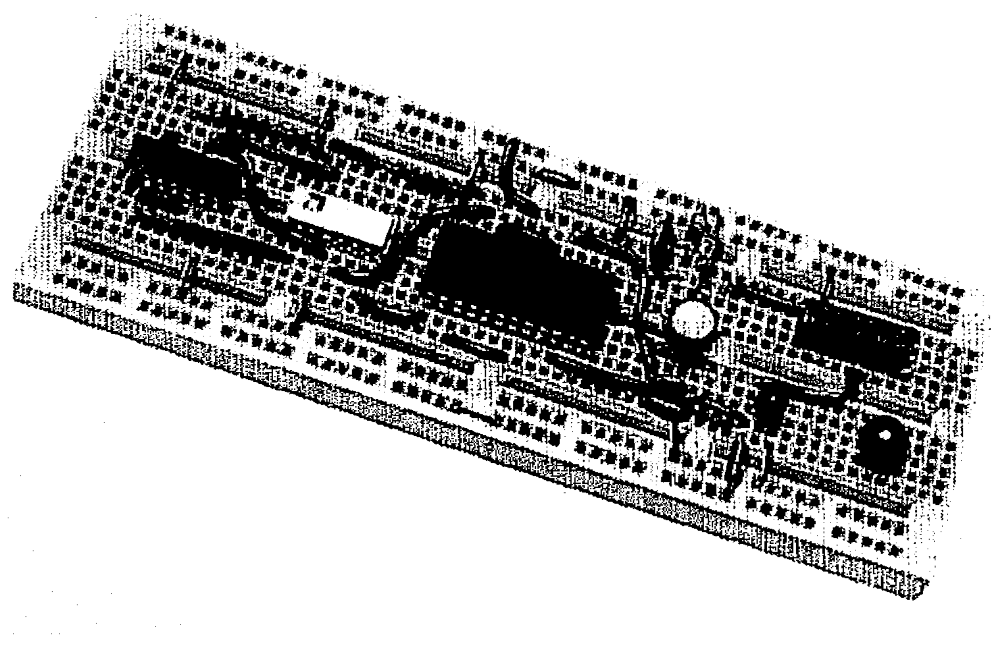
Remember to always use despiking capacitors; small discaps with ultra-short leads, no fewer than one for every four ICs, are essential for proper TTL operation.

If you are using Schottky or high-speed TTL subfamilies, be sure to consult the manufacturer's application notes for further recommendations. Ground-plane type of construction and terminated inputs are sometimes needed with these higher speed subfamilies, particularly in larger systems or where the timing and overlap may become critical. These families are inherently more sensitive to noise since they are faster.

BREADBOARDING AND MOUNTING TECHNIQUES

There is one very simple rule about using perf-board and "rats nest" hand-wired construction with TTL—*DON'T!* One possible exception to this is the newer perf-board techniques where foil tapes are used for lead routing. Here there is at least a chance of minimizing supply distribution problems, provided the foil runs are wide and thin. Careful use of these newer techniques can sometimes be made in simpler systems without too many problems.

There are several good ways to safely and properly mount TTL, both for breadboarding, system tests, and final circuits. One of these systems is shown in Fig. 1-7 and consists of a large plastic block with



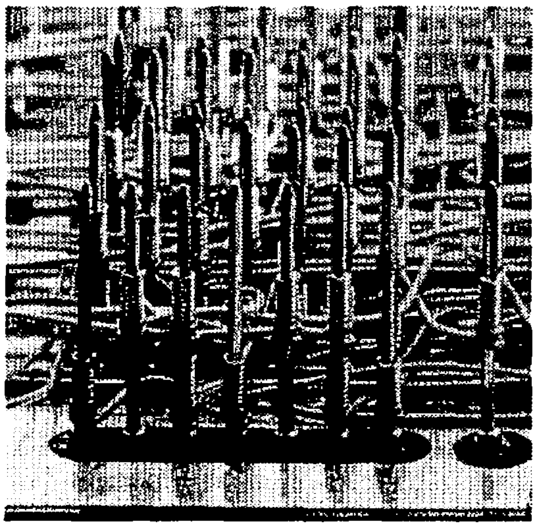
Courtesy API, Inc.

Fig. 1-7. API Super Strip.

integral multiple conductors made of flat strips. Dual in-line packages and other components simply plug in as needed. Wires and components are easily added and removed, and circuit changes are quite simple. While they are somewhat expensive (about $18 for a medium-sized version), they rapidly pay for themselves if you do much breadboarding or rework, particularly on smaller (7 ICs or less) systems. Several firms offer these test modules in complete systems that include power supplies, pulse generators, state indicators, and other support circuitry. These are obviously more expensive, but they are often a good choice where extensive breadboarding is needed.

Wire-Wrap Systems

One widely used industrial mounting technique is wire wrapping, based on socket and panel systems. The ICs push into sockets from the front. At the rear, long pins stick out (Fig. 1-8). Wires are twisted



Courtesy Augat, Inc.

Fig. 1-8. Augat wire-wrap panel.

onto these pins, using special tools. The connection system is as good as soldering, possibly better, and the wires are easily changed and the panels are reuseable. The cost is high ($200 for a medium-sized panel), as are the prices of automatic tools for wrapping and unwrapping. Still, wire wrap often ends up being the most economical route for a medium- or larger-size TTL system where only a few units have to be built or where field changes or customizing are to take place. These boards are starting to turn up as surplus at bargain prices, and hand wrapping and unwrapping tools are also becoming available at reasonable cost.

Sockets

It is usually very easy to remove a TTL IC that has been soldered to a pc board, particularly if a solder syringe or other removal tool is used. Because many of the present day ICs are so inexpensive, reuse is not very practical, particularly if you have to pay someone to remove the old ICs. The obvious exceptions are expensive ICs or systems that are not fully debugged.

Sockets are available for TTL, but often they cost three to five times as much as the IC they are supporting, besides adding bulk and height to the circuit. Sockets are best used in testers and other places where you purposely want to make frequent changes of the ICs in use or under test.

A very interesting and practical solution to the reuse problem is a device that is available through most semiconductor and surplus houses. This is called the *Molex Soldercon* system and is simply a group of prespaced socket pins on a metal carrier, available in numbers of 7, 8, or 12, or as a continuous strip. As many as you need are cut off and simultaneously soldered into the pc board. The common carrier is then broken off and the IC is inserted. Cost is under 1¢ per point, and none of the bulk of a socket is present.

While the *Soldercon* pins are not intended for continuous testing or repeated insertions, they can be reused dozens of times. They do not interfere with most TTL test procedures, and the TTL leads remain solder-free.

One good possibility is to mix direct soldering with the *Soldercon* system. Low-cost ICs can be directly soldered in place, while more expensive or potentially reusable ICs can be "unsocket" mounted.

PC Boards

Printed circuitry gives the best overall control and the lowest installed price for TTL, provided the system is complete and checked, and provided there is enough volume to justify the costs of the initial pc layout.

One approach is to use "universal" pc boards. These are available from several sources and are listed in most distributor's catalogs. They consist of a pc board with several dozen DIP patterns, often with supply runs connected and despiking capacitors present or provided for. You then add ICs and wires as needed for your complete system. Changes are easy to make, and the boards are theoretically reusable, although the component removal effort often exceeds the replacement cost.

Sometimes, construction projects in technical magazines offer pc boards already etched, drilled, and marked for a particular project. As these usually have amortized several hundred or even a thousand dollars of layout, mask, and process time, they generally are a bargain. Services are also available that deliver a pc board to you in exchange for the artwork. Cost, quality, and services offered vary with the company. Unless a firm is specially set up for a rapid turn-around service, charges above $20 per board are typical.

You can also do your own pc layouts, either on a 1:1 basis or on the more accurate 2:1 or 4:1 photographic reduction systems. Pc materials are usually carried by most electronic distributors.

Newer pc processes use ammonium persulfate etchant and are generally less messy and better behaved than the older ferric chloride systems. Best results with ammonium persulfate may be obtained by supporting the board to be etched upside down and having it well-covered by the solution at a temperature of 90 to 100 degrees F. New developers such as CAE Dye-Veloper have an integral dye that lets you verify if the pattern is good before etching. The dye is powerful and should only be used while wearing old clothes and in areas where spills will not hurt anything. The mercury catalyst specified for use with ammonium persulfate is highly poisonous. It is best not to use it for short runs or home etching setups. Etching time will be somewhat longer without the catalyst.

One possible do-your-own pc process starts with a 2:1 or 4:1 replica of the desired layout, often built up by taping stock artwork and pc layout symbols on a Mylar sheet. This is then taken to a photolithographer and converted to a 1:1 litho negative at a cost of around $2. A chemically cleaned pc board is then carefully coated with spray-on light-sensitive photoresist such as Dynachem DCR-3140A. The resist is then heated and hardened. You then expose the pc board by contact printing, either in the sun or with a quartz lamp. The board is then developed, etched, and drilled.

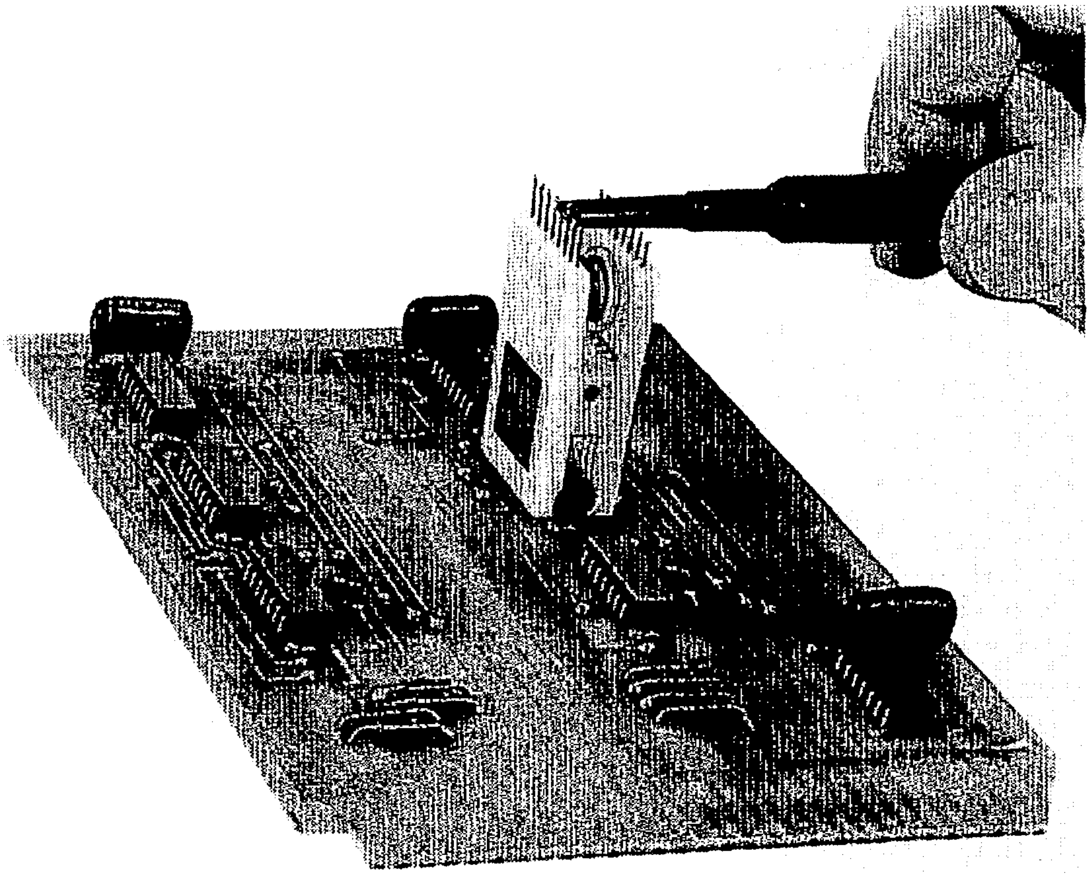
Fancier versions of this basic process let you do double-sided and multilayer boards. If the final layout is relatively simple and is needed in quantity, silk-screen processes are available that are much faster and far cheaper than the one-at-a-time photo processes.

TESTING AND MONITORING STATES

Logic systems are tested, debugged, and serviced by sequentially operating them and comparing the results against what the circuit is supposed to do. This testing can be done *dynamically* at the intended system operating speed, or *statically* on a one-step-at-a-time basis.

Dynamic testing is usually done in conjunction with an oscilloscope. The scope MUST have a triggered sweep and its speed should be good enough to handle the particular circuit problem. A 5-MHz triggered-sweep oscilloscope can handle most routine low-frequency TTL testing, although scopes as fast as 125 MHz may be needed for critical testing of Schottky TTL systems, particularly if delays and overlap are critical.

Static or dynamic testing is greatly simplified with an IC Glomper clip such as the one shown in Fig. 1-9. These clips snap onto an IC and bring out pins for easy testing. One design rule often learned the hard way is to do your pc layouts so that Glomper clips like this will fit. This means keeping resistors and despiking capacitors far enough away from the sides and ends of the IC to let the Glomper clip fit on. End-to-end spacing should also be sufficient, particularly with 14-pin packages, so that the Glomper clip can fit over either end, even if it has 16 pins.



Courtesy API, Inc.

Fig. 1-9. API Glomper clip.

Static testing is usually much simpler than dynamic testing, and it should be done first if something obvious is wrong with the circuit operation. One essential piece of test equipment is called a *bounceless push button,* a circuit that gives you a noise-free single command on request. Several suitable circuits are covered in Chapter 4.

A second essential ingredient to static testing is a *state checker*. This is any means of verifying what the output and input pins of each IC are doing at any given time. At zero or very slow speeds, a voltmeter is an excellent state checker. The 0's should be less than 0.8 volt; the 1's more than 2.4 volts. High-frequency counting chains will give a meter indication halfway between these values if the duty cycle is 50-50 and if the frequency is fast enough that the meter averages out. Do not forget to verify ground and supply voltages when state checking.

A *logic pen* is a state checker that is easier to use. Touching the tip of the pen to the IC pin either lights or does not light one or more lamps, indicating a 1, a 0, or pulsed operation. Some of these units are quite sophisticated and include pulse detection and other elegant circuitry. They are priced accordingly. A simple state checker you can build into a test lead or ball-point pen is shown in Fig. 1-10. The clip lead is connected to the positive supply. The light emitting diode lights for a grounded-output state and remains off for a high-output state. Fan-in is about 6.

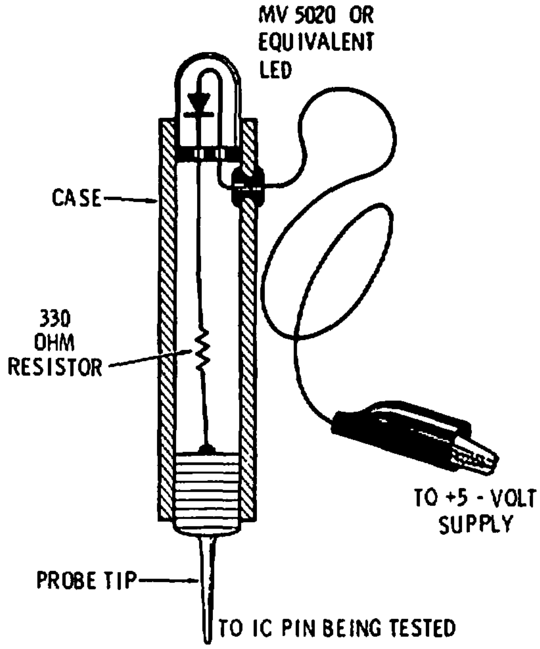
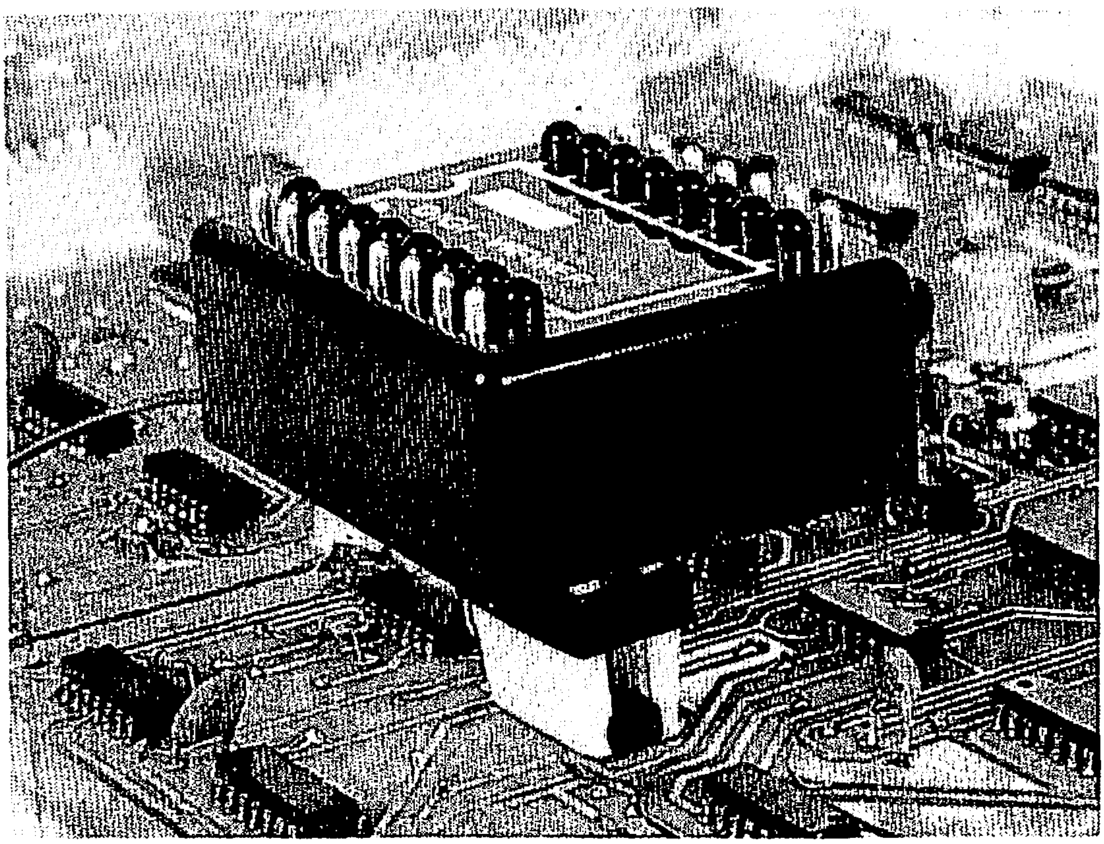


Fig. 1-10. Simple logic-state checker.

A more elaborate state checker (Fig. 1-11) is called the *Digiviewer.* It simultaneously monitors, via a modified Glomper clip, all 14 or all 16 pins of an IC under test. The states are displayed on panel lamps. A slide that shows the circuit for the IC under test fits over the panel lamps. In this way, the states are easily related to their logically similar pins.

Any of the slow or static test methods are useful for servicing, checking for good ICs, or testing circuits of proven design. They also can indicate the presence of a brief pulse, such as those generated by a counter being reset or something similar. Various techniques of checking duty cycle vs voltage or brightness will indicate whether counting chains are operating. They usually will not indicate problems caused by glitches, high-frequency pulse overlap, improper setup times, or other inherent high-speed problems, possibly caused by a poor circuit design. Two other minor limitations are that they might give a "wrong" logic indication of an unterminated, open-collector output stage, and the capacitive loading caused by the test cable can upset a very few TTL devices such as monostables and high-speed Schottky counters.



Courtesy Popular Electronics

Fig. 1-11. Digiviewer logic state checker.

INTERFACE

Getting signals into and out of TTL is called *interfacing*. There are three types of interface: TTL to TTL, TTL to other logic, and TTL to outside world.

TTL to TTL

We have already seen that most TTL circuits can be directly connected to any of the others, so long as fan-out rules are observed. Whenever you interface between TTL subfamilies, you have to be very careful about the available fan-out. For instance, most low-power TTL gates will only drive two regular TTL gates. Regular TTL will only drive 6 or 7 high-power TTL or Schottky TTL inputs. Low-power Schottky can only drive 3 regular TTL inputs or 1 high-power or Schottky TTL input. Some of these relationships are shown in Chart 1-5.

As a general rule, any given subfamily has a fan-out of 10, except for a few buffer circuits with higher fan-outs, typically 30. Some old TTL designs had fan-in requirements of 2 and sometimes even 3 loads on certain inputs, but the majority of new designs have a fan-in standardized at 1 when referred to its own subfamily.

Chart 1-5. Some TTL Subfamily Fan-out Rules

Regular TTL	Will drive 10 regular TTL inputs Will drive 40 low-power TTL inputs Will drive 6 high-power TTL inputs Will drive 6 Schottky TTL inputs Will drive 20 low-power Schottky TTL inputs
Low-Power TTL	Will drive 2 regular TTL inputs Will drive 10 low-power TTL inputs Will drive 1 high-power TTL input Will drive 1 Schottky TTL input Will drive 5 low-power Schottky TTL inputs
High-Power TTL	Will drive 12 regular TTL inputs Will drive 40 low-power TTL inputs Will drive 10 high-power TTL inputs Will drive 10 Schottky TTL inputs Will drive 40 low-power Schottky inputs
Schottky TTL	Will drive 12 regular TTL inputs Will drive 40 low-power TTL inputs Will drive 10 high-power TTL inputs Will drive 10 Schottky TTL inputs Will drive 40 low-power Schottky TTL inputs
Low-Power Schottky . .	Will drive 5 regular TTL inputs Will drive 20 low-power TTL inputs Will drive 4 high-power TTL inputs Will drive 4 Schottky TTL inputs Will drive 10 low-power Schottky inputs

Usually, 7400-Series regular-power TTL can be freely intermixed with Motorola 4000-Series MTTL or Signetics 8200-Series TTL, although you should always check the individual data sheets to be sure. There are sometimes slight differences in output high voltage due to different types of totem-pole output design. These do not affect TTL-

Table 1-4. Comparison of Output Current and Input Needs

TTL Subfamily	Output Provides	Input Needs
Regular	16 mA	1.6 mA
Low-Power	3.6 mA	0.18 mA
High-Speed	20 mA	2.0 mA
Schottky	20 mA	2.0 mA
Low-Power Schottky	8 mA	0.4 mA

to-TTL interface but can make a difference in going between logic families. For instance, some 8000-Series TTL will directly interface with MOS without needing a pull-up resistor, while a 7400-Series usually needs one.

Table 1-4 compares output low-state current with input low-state needs for the various families. If you have a more complicated intermix, simply add up the input currents you need to drive it and make sure the sum is less than the available drive capability. In wide-temperature designs or where you are driving a large number of inputs, the high-state currents need also to be considered for exactness. Values in Table 1-4 have been conservatively rounded off to eliminate having to make this calculation for most circuit problems.

TTL to Other Logic

Interfacing between logic families is usually easy to do, but there are several problems. You must select the supply and ground connections between the families to optimize the logic states. You have to honor the output voltage and current swings of the one logic family and provide the minimum 1 and 0 conditions of the other. For detailed interfacing information, you have to carefully study the manufacturer's data on the IC line to be interconnected. However, Figs. 1-12 through 1-16 give some general interface guidelines that usually work.

RTL—RTL to TTL or vice versa may be directly connected (Fig. 1-12). Grounds of both systems are common, and the RTL may be driven from its usual 3.6-volt positive supply or from a 5-volt TTL supply. No RTL loads should be presented to an RTL device that is driving TTL.

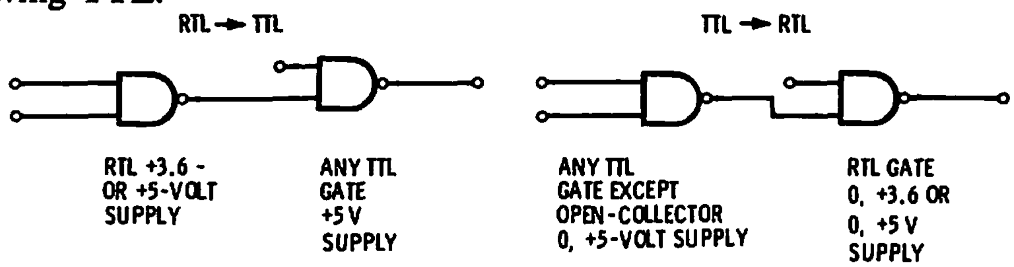
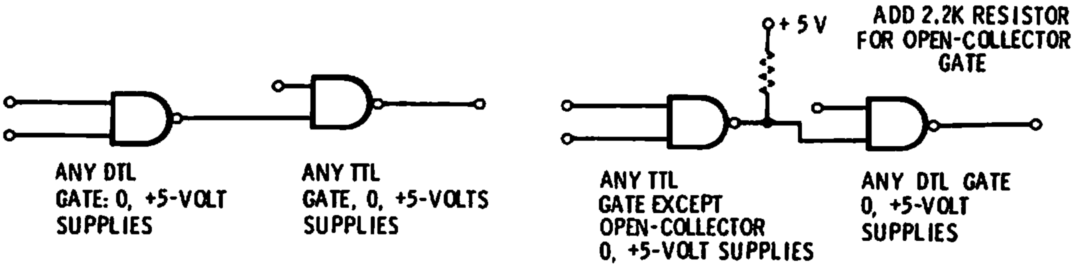


Fig. 1-12. RTL-to-TTL and TTL-to-RTL interfacing.

DTL—DTL to TTL and back again are usually directly compatible (Fig. 1-13). Consult data sheets for fan-out information.

MOS—Silicon gate or n-channel low-threshold MOS sometimes needs a pull-down resistor on its outputs to properly drive TTL (Fig. 1-14). When TTL drives MOS, a *pull-up* resistor is usually needed. TTL fan-out into MOS is very high, but MOS fan-out into TTL is usually one input and often you cannot simultaneously drive MOS and TTL. Older, high-threshold PMOS families may need open-collector outputs and pull-up resistors on the TTL drivers if the positive sup-

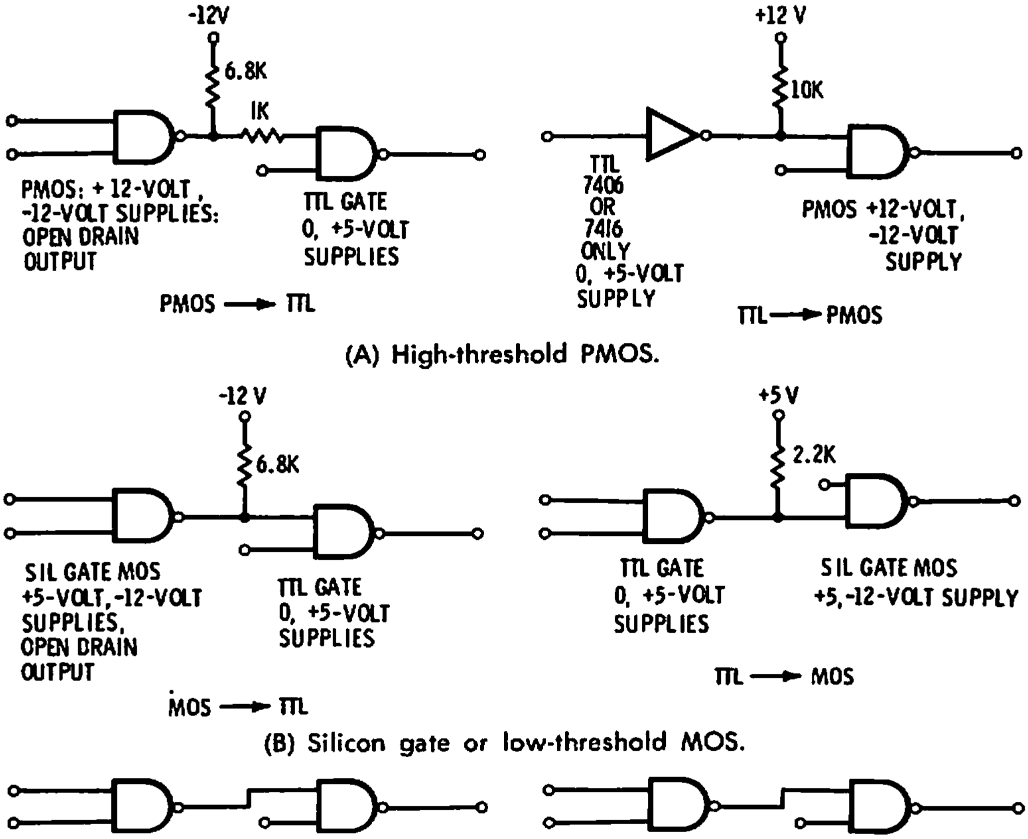


(A) DTL to TTL. (B) TTL to DTL.

Fig. 1-13. DTL-TTL interfacing circuits.

ply voltage is +12 V. Older MOS runs on a +12-V, −12-V supply system. Newer silicon-gate MOS runs on +5 V, −12 V, and the +5-V supply should be common with the +5 V of the TTL. Newest of all is n-channel MOS. It usually works on a single +5-V supply and is directly compatible with TTL.

CMOS—CMOS (Fig. 1-15) can directly drive low-power TTL. It can drive *one* regular-powered TTL input if a device is chosen with two parallel transistors to ground, as shown in Fig. 1-15, or it can drive several TTL inputs, using a buffer, such as the CD4049 or CD4050. TTL can directly drive MOS, although noise immunity is

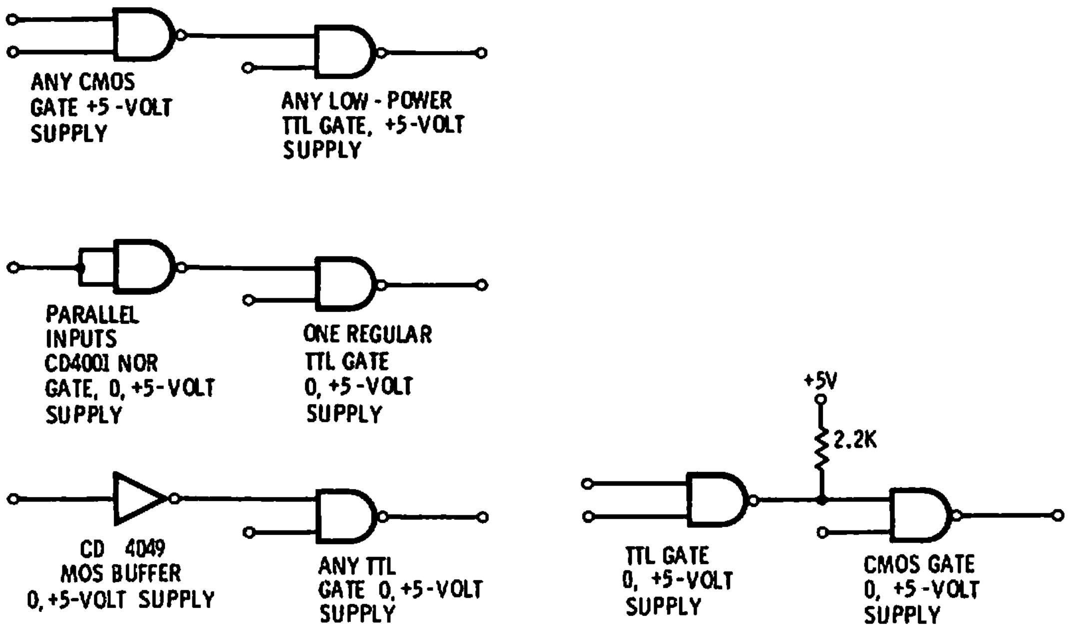


(A) High-threshold PMOS.

(B) Silicon gate or low-threshold MOS.

(C) N-channel MOS (single +5-volt supply).

Fig. 1-14. Some typical MOS-to-TTL interfacing techniques.



(A) CMOS to TTL. (B) TTL to CMOS.

Fig. 1-15. TTL-CMOS interfacing.

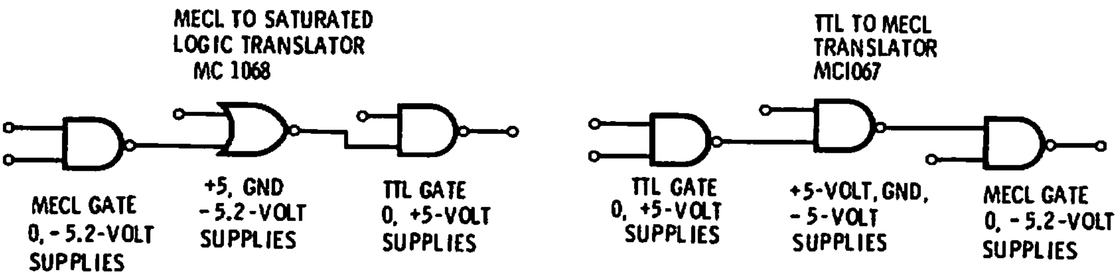
improved with a pull-up resistor. The minimum TTL high state should be well above one-half, but less than the positive MOS supply voltage.

MECL and ECL—Emitter-coupled logic families (Fig. 1-16) have unique logic swings, and it is difficult to build simple interfacing. Instead of this, commercial IC logic translators that do the job quickly and reliably are readily available.

If the family to be interfaced has wildly different supply- and voltage-swing restrictions or if it is on an entirely different power-supply system, a more elaborate interfacing system can be used. One possibility is to use optical couplers that isolate both signal and ground. A second possibility is to use integrated-circuit line drivers and receivers for translation. Be sure to consult individual data sheets when intermixing IC families.

TTL to Outside World

In a sense, this entire book explains how you use TTL processing to get from outside-world signals to a group of outside-world outputs.



(A) MECL to TTL. (B) TTL to MECL.

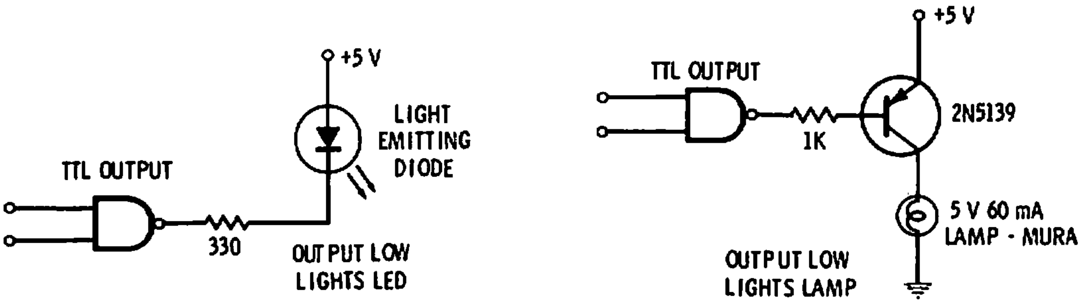
Fig. 1-16. TTL emitter-coupled logic interfacing.

We will pick up much more detail as we go along, but the general concepts of interfacing are as follows.

At a TTL input, you have to guarantee a current-sinking capability of at least 1.6 milliamperes at a voltage of 0.8 volt or less for a low-input condition. You also have to guarantee a minimum voltage of +2.4 volts and provide only for a leakage current as an input-high condition. The input swings cannot normally be allowed to exceed the positive supply or go below ground.

The high-to-low transitions and vice versa must be very fast, and one and only one transition can be allowed per intended input change. This means push buttons and other mechanical contacts must be suitably conditioned to make them bounceless and noise free, and that low-frequency and analog signals must have snap-action added to them to improve the rise time. These techniques are further covered in Chapter 4.

TTL will directly drive a light emitting diode, provided a suitable current-limiting resistor is placed in series, as shown in Fig. 1-17A. Incandescent lamps can be driven with a small transistor, as shown in Fig. 1-17B. Note that the output-*low* condition on TTL is more suitable to provide lots of current. Interface to the outside world should optimize this fact.



(A) LED.

(B) Incandescent lamp.

Fig. 1-17. TTL lamp drivers.

TTL-to-analog conversion may be done simply with 1K, 2K, 4K, and 8K resistors summed into an op-amp, or TTL-compatible D/A converter ICs, such as the Motorola MC1406 and MC1408, may be used.

In general, any interface system requires that you rapidly and bouncelessly provide guaranteed input-high conditions (high voltage/low current) and guaranteed input-low conditions (low voltage/high current) at all TTL inputs without exceeding the supply or going below ground. In addition, it requires that you stay within the current and voltage limitations of the TTL output stage. Chapter 6 discusses more output interface circuits, particularly those dealing with readouts.

TOOLS

All of the small hand tools used for electronics can be used for TTL work, with the "jeweler"-sized tools being preferable to the larger "electronic" ones. Traverse-cutting pliers are particularly handy for TTL lead cropping. A small soldering iron with a fine tip is a must. One good combination is an Ungar 1235 unit of 40 watts with a PL-338 tip.

Some means of removing ICs is also needed. A solder syringe and its wire cleaner is one good route to take, while solder-removing capillarity braid is another.

A miniature pin vise with a No. 68 drill is handy for cleaning pc board holes and adding components, while a carbide-tipped machinist's scriber is one easy way to open a run on a pc board, but still allow a "solder blob" to fill in later.

A good pocket magnifier, a high-intensity lamp, and a hobby knife with renewable blades are some useful items to have on hand when working with TTL.

You will almost certainly want to add a homemade bounceless push button, a Glomper clip or two, and a state checker to your basic tools. These are almost essential for any work with TTL.

"BAD" AND "BURNED OUT" INTEGRATED CIRCUITS

Occasionally you will get a faulty IC—maybe one or two out of a hundred from a quality distributor, perhaps a few more from a surplus source unless you are obviously buying seconds. TTL ICs will also withstand more than a reasonable amount of abuse, including output shorts, brief applications of reversed supply polarity, excess voltage, and so on. In short, TTL ICs are reliable and rugged.

There is a tendency to blame the poor IC for every circuit problem, including incorrect logic design, pc layout errors, shorted outputs, solder blobs, lack of pull-up resistors on open collector outputs, unconnected supply leads, layout mixups (watch the 7400 and 7402!), poor supplies and bypassing, layouts done topside and etching done backwards, floating inputs, etc.

If an experimental or breadboard circuit appears defective, the problem is almost never a bad or burned-out IC. Every other possibility should be exhausted before an IC is replaced. The rule, and this is the hardest one in this book to learn, is simply: *Always blame yourself first, the IC last.* If you follow this rule, you will find that it saves time and money 99% of the time.

By the same token, if you ever do find a genuinely bad IC, be sure to destroy it so it does not work its way back into some other circuit later on.

SOME CONVENTIONS

In the rest of this book, we have omitted the obvious connections to an integrated circuit in order to make the circuit function we are trying to show more apparent. This is very common in all digital logic circuits. Thus, every circuit in the book needs a +5-volt, regulated and properly despiked supply and a ground return connected to all ICs in use. All unused input leads must go somewhere—disabled to +5 volts or (very rarely) ground, or tied to a logically similar input. Presets, preclears, enables, inhibits, and other control pins must be properly provided for. These connections are all shown in Chapter 2 and on the data sheets. As you go from circuit to breadboard, be sure not to overlook any of them.

We also have not tried to keep track of fractional ICs. A "7400" callout usually means one-quarter of a 7400 NAND gate. A "7473" usually means one-half of a 7473 dual JK flip-flop, and so on. As you use a circuit, be sure to check back to Chapter 2 or the manufacturer's catalog to see how many of these you get per package, and what all the remaining pins on the package do. Output leads that are unused should be left unconnected; all others must go somewhere.

CHAPTER 2

Some TTL Integrated Circuits

This chapter is primarily a catalog of the more popular TTL circuits. It differs in several ways from the detailed information you are likely to find in a manufacturer's catalog.

First, it covers only the essential information you might need to connect or intelligently use the integrated circuit. Second, it includes only the more popular devices, the ones you are most likely to be using.

Third, it is an industry-wide selection that favors no particular manufacturer or product line. It includes non-TTL and support devices (timers, regulators, etc.).

Finally, and most important, this chapter explains as simply as possible what the circuit does and at the same time points out use restrictions or hangups.

As an additional aid, particularly when you are working with several ICs at once, the information in this chapter is also available on a large poster (Catalog No. 21080). You can wall mount this poster for instant reference for TTL layout and servicing work.

Unless otherwise noted, all the listed parts need a +5-volt regulated and despiked supply and operate with a fan-in of one load and a fan-out of ten loads. Only the regular TTL subfamily is shown; other subfamilies usually have identical pinouts.

An *input-low* state means the input is pulled below +0.8 volt and 1.6 milliamperes is being pulled out of the input. An *input-high* state means the input is being held more positive than 2.4 volts and that a small leakage current is being provided.