HOW TO DESIGN TTL DIGITAL SYSTEMS

tips for the circuit designer on using the popular Transistor-Transistor Logic family

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DIGITAL circuits and techniques are finding their way into all areas of electronics, including many of the "all-linear" circuits of just a few years ago. Because of this ever-increasing popularity, it behooves the electronics experimenter to sharpen his knowledge of digital circuits and devices. The focus here is on the popular and low-cost transistor-transistor logic, or TTL, family of digital integrated circuits.

The TTL Family. The transistor-transistor logic family uses built-in transistors both as electronic switches and gates, is highly immune to noise, and has very fast operating speeds. The most common forms of the TTL family are the industrial-grade 7400 and military-grade 5400 series. Some manufacturers have 8000 and 9000 series of TTL devices. There is no relationship between the type of IC function and the last two digits in the IC's identifying number. A 7400 is a quad NAND gate, while a 7490 is a decade counter.

Within the 7400 series, letter designations are often added to further identify the type of IC. For example, the 7400 is a standard four-input NAND gate, but the L in 74L00 identifies the IC as a low-power four-input NAND gate. To get this characteristic, one sacrifices speed. The H in 74H00, on the other hand, tells us that this is a high-power version of the same IC. Its output stage can drive higher current loads and is capable of driving normal loads faster because of its ability to charge the inherent output capacitance at a faster rate.

The 74S00 is a fairly high-power device that is extremely fast because its inputs are clamped by Schottky diodes. These diodes have very fast switching characteristics and thus make the 74S00 series the fastest of the TTL devices. The Schottky diode approach has been combined with the low-power approach to produce the 74LS00 series. The typical 74LS00, for example, consumes very little power, yet it operates at speeds as high as the conventional 7400 device.

Each of the types of TTL devices described above has its place in your circuit designs. Your choice of devices will be dictated by the power and speed requirements of your specific project.

Application. TTL IC's have very good noise immunity characteristics and operate with a good tradeoff in speed. Even so, they must be used with some care in circuit design to minimize interaction between elements. For example, in Fig. 1, gates A and B can suffer from unwanted coupling through the invisible but very real inductance of the common ground lead that ties the two gates to the negative side of the power supply line and the input to buffer C that is not supposed to operate at this time.

When gate A discharges the stray capacitance at its output, an erroneous signal appears because of the ground inductance at gate B. These undesirable outputs are commonly called "glitches." They can be eliminated mostly through proper circuit layout. The way to do this is illustrated in Fig. 2. Here the ground interconnection between the two gates is a "bus" lead.

Assume that gate A in Fig. 2 is a low-power 74L00 series IC and that buffer B is a high-power 74H00 device. As soon as the high-power stage switches on, a high-speed, high-current switching transient is generated and causes a voltage drop through the resistance of the ground or V+ bus. This voltage is applied to the input of the low-power gate, which "sees" it as a real signal. The usual remedy for this situation is to use bypass capacitors directly at the V+ and ground pins of the IC's. Proper circuit layout, however, can minimize glitches in the wiring without the need for bypass capacitors.

An example of bypassing is shown in Fig. 3. Note that there still exists a slight variation in the power supply along the bus and that although the transients (compared to Fig. 2) are almost eliminated by the bypass capacitors, the high current drain will still affect the voltage at one end of the bus. The point to remember in designing TTL circuits, and any other logic system, is that it is best to know what will be the effect of an action taken rather than attempt to make up for inadequacies after the fact.

The best way to lay out a TTL logic system is to use the V+ bus and ground-plane approach. Ideally, it would be best to have all V+ points in the circuit on one side of the board and all ground points on the other side. Unfortunately, circuit considerations dictate otherwise, since interconnections between elements must be made somewhere. However, it is possible to simulate the V+/ground bus approach by using the layout illustrated in Fig. 4. IC's can be

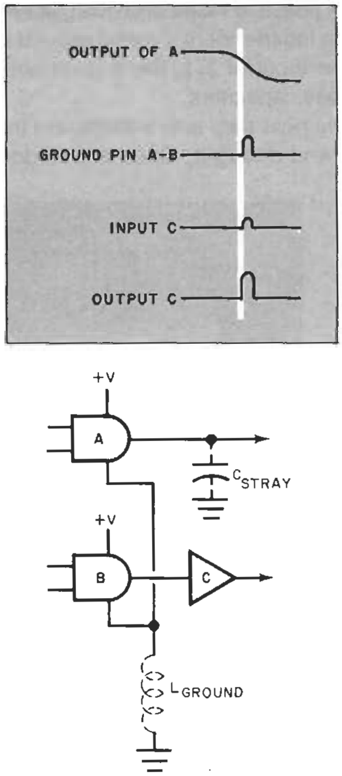

Fig. 1. Common ground inductance and stray capacitance cause "glitch" at output gate of C.

distributed along this bus system. Each of the two buses appears on both sides of the board. It matters little that each bus begins on one side of the board and ends on the other; electrically, each is a continuous bus.

The Fig. 4 approach lessens the effect of distributed capacitance, while the capacitors at the points where the buses cross over through the printed circuit board are adequate for bypassing. If this type of layout is not possible, it is best to locate the ground bus entirely on one side of the board and the V+ bus entirely on the other side of the board.

High-current devices should be located as close as possible to the V+ and ground bus connections. This will assure a minimal effect by these devices on the more sensitive, lower-current devices in the circuit. Bypassing at the input stages will then have greater effect.

Once you have fabricated a pc board for a certain digital function, you may find it necessary to include more than one pc board assembly in your finished system. In this case, each pc assembly must be designed to minimize the inherent stray inductance and capacitance and heavy bus structures should be used to connect the V+ and ground lines to all boards. In some cases, it may even be necessary to use separate ground leads to high-power circuits.

Design Hints. The first step in designing a logic system is to lay it out on paper. The next is to breadboard your layout. While you are breadboarding the circuit, try to use the same physical layout you plan to use in the finished project. This will reduce the chances of any surprises after you etch a pc board and are committed to a given layout.

In the breadboarding stage, there are a few things to keep in mind. The popular "solderless" breadboard has a distinct problem—there is very high capacitance between the interconnecting strips within the socket. At high frequencies and at very fast switching speeds, capa-

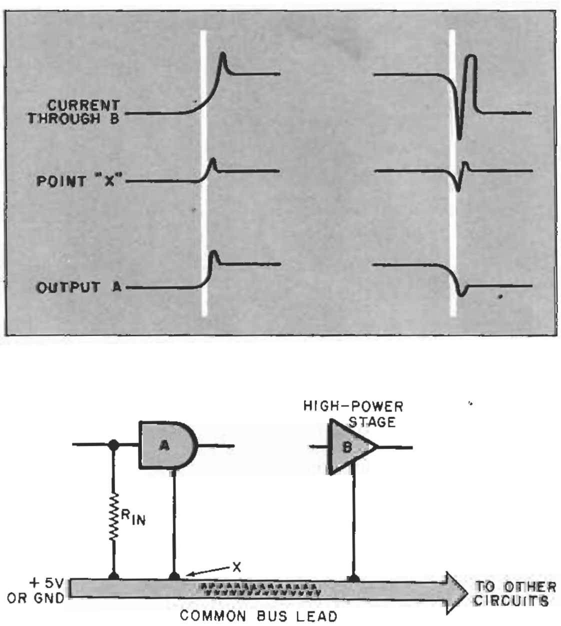

Fig. 2. Both glitch and voltage drop can occur along a common bus lead as shown here.

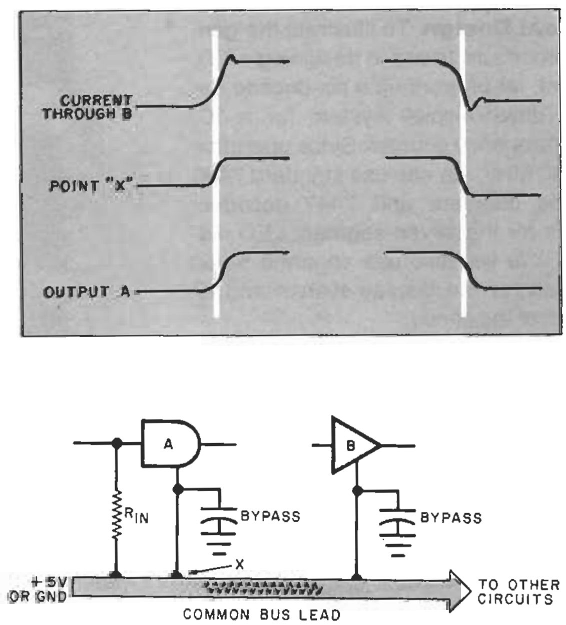

Fig. 3. Bypassing can eliminate glitch but not voltage change which produces erroneous signal.

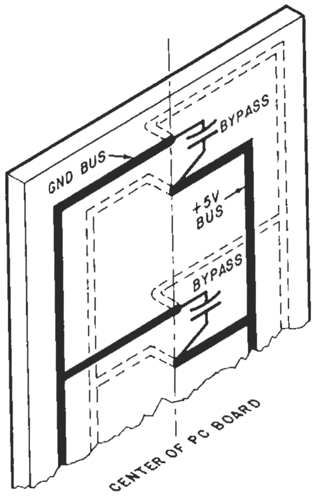

Fig. 4. Ground plane simulation where buses start on one side of board and cross to other side, with bypassing at crossovers.

citive coupling may occur between the closely spaced internal "tracks" or between the holes on the board. Do not use these breadboards for high-frequency circuits. They are, however, adequate for breadboarding low-frequency circuits in which the switching speeds are low.

The last and perhaps most important design stage is to debug the circuit you set up on the breadboard. To do this, you will need certain test equipment, such as an oscilloscope or logic probe. The logic probe is handy to have in cases where your scope has a limited bandwidth that prevents it from registering on-screen fast pulses. Almost any type of multimeter can be used to check for the presence of the proper dc voltages on the various IC pins.

Typical Design. To illustrate the general procedure to use in designing a TTL system, let us work up a six-decade decoder/driver/display system for a 30-MHz frequency counter. Since operation is to 30 MHz, we can use standard 7490 decade counters and 7447 decoder/drivers for the seven-segment LED displays. We will also use separate 5-volt supplies for the display system and IC portion of the circuit.

First, we would start by laying out on paper the basic circuit configuration. Then, we circle the portions of the system that draw high current, as shown in Fig. 5. The areas of highest current demand are the outputs of the 7447 LED drivers and the LED displays, neither of which are required to do high-speed switching. The highest speed device in this circuit is *IC1*, which must operate at frequencies up to 30 MHz. Consequently, this IC must be located at the point of least possible noise and bus glitches. By using independent V+ and ground leads at the input of *IC1*, there is no need for bypass capacitors.

The next step is to breadboard the circuit and debug it. Once this is done, a printed circuit board can be made. An actual pc assembly for this circuit is shown in Fig. 6. Note that the pc board has copper traces on both sides of the board, which eliminates the need for separate wire jumpers to interconnect all points in the circuit.

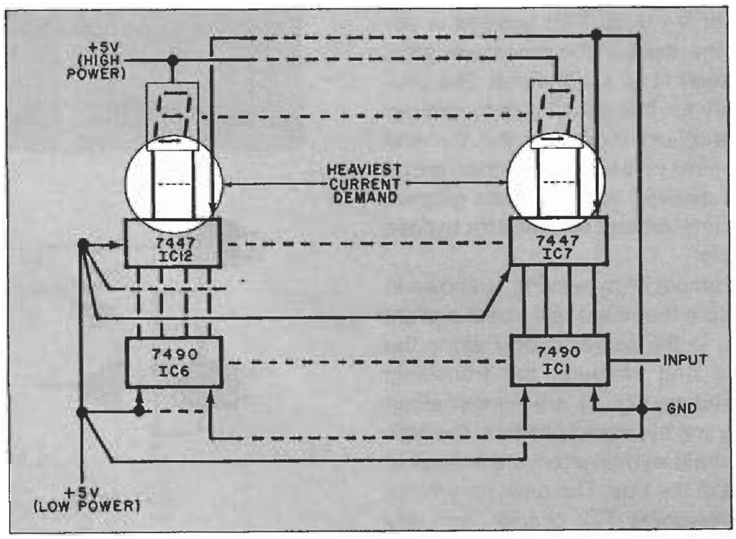

Fig. 5. Sample circuit has independent grounds and supplies to reduce glitches. Circled areas have own supply leads.

Closing Remark. As you can see from the foregoing, designing with TTL is relatively easy—if you give careful attention to circuit layout. One way you can get a "feel" for proper design is to experiment with the various types of TTL IC's available at low cost from the advertisers in the back of this magazine. ◇

Fig. 6. The final layout of the decade counter follows the general outline suggested in Fig. 5.