INTRODUCTION

(EE2499_Introduction.doc revised 1/1/18)

A. PARTS AND TOOLS:

This lab involves designing, building, and testing circuits using design concepts from the Digital Logic course EE-2440. A locker (plus lock) in the lab room C-251 containing parts and equipment will be checked out to you for the duration of the quarter. The equipment includes:

☐ A breadboard (also referred to as a protoboard) where you will build your circuits. The breadboard comes with a test circuit (already connected) which you will use in testing your designs.

☐ Several cables (for use with power supply and oscilloscope).

☐ Wire cutter/stripper tool for cutting wire and stripping the ends for insertion in the breadboard.

☐ IC (integrated circuit) chips for building circuits you design in the various experiments.

☐ Logic probe: this is the main tool you will use in the lab for troubleshooting your designs.

There are additional items not supplied in the lab:

USB flash drive: you'll need this to store waveform data captured on the oscilloscope screen and to transfer it to a PC.

Lab Journal: you'll need to purchase a composition book to record your prelab work (design work including truth tables, K-maps, state tables, state machines, logic diagrams, and wiring diagrams), your lab experimental results (including your observations, results – waveforms, truth tables, and state tables/machines), answers to any questions posed in the lab manual, and any notes that you take related to the experiments.

B. CIRCUIT DIAGRAMS:

Your circuit diagrams should serve two functions:
- logic diagram--to show the flow of logic in your design.
- wiring diagram--to guide you in making circuit connections.

It is recommended that you draw your circuit diagrams directly in your lab journal (though if you want to use schematic capture software you can but you should cut and paste the diagrams from your prelab work into your lab journal before lab). However, when you submit a laboratory report, you'll need schematic capture software to draw circuit diagrams clearly and neatly. You will be responsible for submitting typed laboratory reports for experiments 3, 5 and 6 combined, and 10.

For your laboratory reports, use the "schematic capture" program ExpressSCH (a part of ExpressPCB) to draw your circuit diagrams. Download and install ExpressPCB early in the quarter—you'll need it starting with Experiment 2. See the instructions in Part2 of the Appendix at the back of that experiment.

With ExpressSCH, the following requirements will be easy to meet:

a) In order to make circuit logic as clear as possible, gate and flip-flop symbols should be shown separately--not together inside a chip rectangle as they are shown at the end of this manual. That way,
they can be placed individually in a diagram wherever it is convenient. Only when a chip acts as a *single unit* (counter, MUX, etc.), not a collection of identical elements, is it represented as a rectangle.

Where the unit is shown as a rectangle (counter, MUX), pins are not shown in their true positions around the rectangle. Instead, they are arranged to make the logic flow easy to follow, logic inputs at the left, outputs at the right. Control inputs (e.g. clock, reset, enable) can appear at the left or at the top or bottom of the rectangle.

b) Active-low inputs and outputs are shown with small inverting circles. Alternatively, a bar above a variable's name or a forward slash before it (i.e. /X) indicates inverted logic. These symbols are very helpful when following logic flow or troubleshooting a design.

c) In all rectangles, pin names (e.g. D,Q for flip-flops, Cin for adders, Clk for counters, etc.) are shown inside, pin numbers outside. Chip part numbers are placed next to the device symbols (e.g. 7432 next to an OR-gate symbol).

d) Each rectangle and gate symbol should contain a "U" (Unit) number. In the case of gates and flip-flops, these unit numbers identify which chip they are part of. Suppose your design involves six 2-input NAND gates, four gates to a chip. You will need two 7400 chips. Suppose you number these U2 and U3. Then four gate symbols might be designated U2, the other two U3. A connecting wire from pin 3 of U2 to pin 9 of U3 could then be described as "U2-3 to U3-9". A number system such as this will do much to speed up the troubleshooting process. One partner can call out each connection from the diagram while the other partner checks the circuit to see if the connection has been correctly made.

e) Your circuit will be laid out as a line of chips (with spaces between so you can lever a chip out if it needs replacing). All chips will be facing left as shown in the diagram on the next page. In your diagram, label the left-most chip U1. Then the next chip from the left would be U2, etc.. This will make it easy to associate chip components (like gates) on the diagram with the physical chip on the board.

Different gates or flip-flops within a chip can be assigned a different label, e.g. A, B, C. etc. Suppose the first chip on the left is a 7474 which you label unit 1 (U1) on the diagram. Now, 7474's have two D flip-flops. Thus, U2A could refer to one flip-flop and U2B could refer to the other flip-flop. However, the flipflops can also be told apart because they each have different pin numbers, so the labels A, B, etc. aren't really necessary. Make sure when drawing a diagram, that no two gates or flip-flops show the same pin numbers *unless they belong to different chips*. Later, when connecting your circuit, make sure that you use the *same pin numbers* as shown in your diagram.

Much of the above will also be found Appendix, Part2 at the end of Experiment 3.

C. TEST CIRCUIT:

On page 6, you will find a layout diagram of the circuit to be used in testing your experimental designs, followed on page 7 by photographs of two parts of the circuit. The test circuit occupies the lower section of the breadboard; the remaining area, above the test circuit, is where you will implement your designs.

The diagram below represents one strip of a breadboard--yours will have four such strips. (Terminals for connecting 5V and ground are not shown.) For the following discussion, we will assume that you aree viewing the breadboard from a "landscape orientation" – meaning that the width is longer than the
height.

The very elongated narrow horizontal rectangle represents a depression along the center of the strip. An IC chip is inserted into holes above and below the depression, as shown. Each chip should be pointed to the left so that its pin #1 is at the lower left corner.
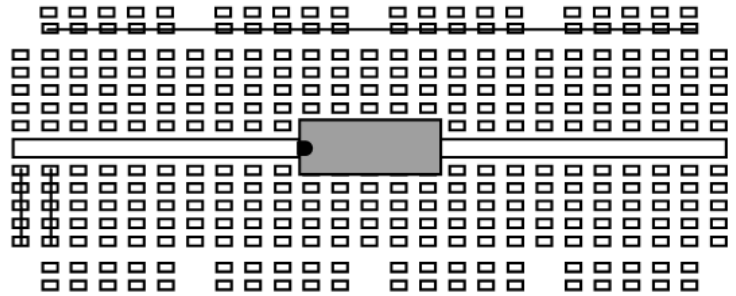
There are two ways manufacturers specify the pin #1 end: (a) a semi-circular notch at that end (as shown here), or (b) a circular depression at each end, with the deeper of the two at the pin #1 end.

The vertical lines through two of the 5-hole columns show how the holes in every column perpendicular to the center depression are connected together beneath the board. Thus, the voltage at each pin of a chip is available in the 4 adjacent holes for connecting to other devices.

The rows of holes (in horizontal groups of 5) that run alongside the main blocks of holes, are used as power (5V) and ground buses. Near the top of the diagram, there is a line drawn through one row. This line shows how the holes in all such rows are connected together beneath the board, so that power and ground can be carried from one side of the board to the other.

Not shown in the diagram is a pair of buses which run vertically down one side of the board. These are connected to the external power supply and ground, and then to each of the horizontal buses. This will distribute power (5V) and ground (0V) around the board. The horizontal buses are identified by blue and red lines running alongside the holes. The blue lines identify the ground buses; the red lines identify the power buses.

The test circuit consists of the following sections (starting at the left side of the layout diagram):

1. PULSER CIRCUITRY--there are two pushbutton switches, each having normally-open and normally-closed contacts. The outputs of each switch are sent through a NAND debouncing circuit, and the NAND outputs are identified as "normally low" and "normally high". In this case "normally" means when the button is not being pressed. When the button is pressed, the normally-low output goes high, and the normally-high output goes low. When the button is released, the outputs return to their normal levels. (See photo and discussion on pg. 7.)

Normally Low   Normally High
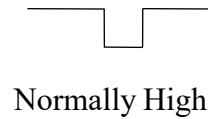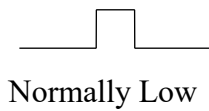
2. LED DISPLAY--there is a 10-LED "bargraph" chip next to the NAND chip. It should be inserted in the board with the small corner notch at the upper right (as shown on pg.6). The chip voltages you wish to display are brought to LED inputs (above the LED chip in the diagram). When a voltage goes high, current flows down through an LED and then into one end of a SIP resistor. The other end of the resistor, in common with all the others in the SIP, is connected to the ground (blue) strip at the bottom of the circuit.
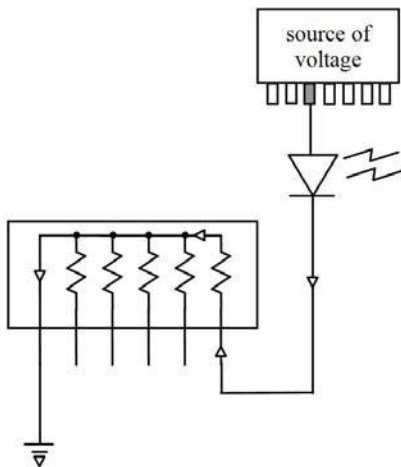

"SIP" RESISTOR ARRAY

SIP (Single In-line Package--only one row of pins)The SIPs used in this lab vary in color and number of pins. In this example, it has 6 pins but only 5 resistors. The pin at the end marked with a dot is the "common". For this circuit, the common is connected to 0V (ground) while the pins in the resistive legs are brought to the cathodes of the LEDs. A marking like 331 means $33 \cdot 10^1 = 330\Omega$ for each resistor. (Similarly, 103 would mean $10 \cdot 10^3 = 10K\Omega$.)

Outside view   Inside view

3. FREE-RUNNING CLOCK--a 555 timer chip is connected as an oscillator. Oscillation frequency is determined by an RC circuit. There are two R's, a 2.2KΩ and a 470 Ω, and there is a choice of two capacitors: C1 = 0.47 μF and C2 = 470 μF (μ = micro = 10^{-6}). Whichever capacitor is chosen, it is charged up to a maximum through the two R's in series, 2,670 Ω, but discharged down to a minimum through the 470Ω alone. While the capacitor is being charged, the timer output is high; while it is being discharged, the output is low. Since charge and discharge times depend on circuit resistance, the output is high much longer than it is low resulting in an unsymmetrical rectangular waveform. (This can be seen by displaying the timer output on an oscilloscope.)
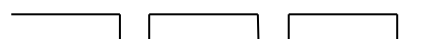
Note: C2 is an electrolytic capacitor, it is "polarized"; i.e. it has a positive and a negative terminal. The voltage at the positive lead must always be greater than that at the negative. There is a stripe down the side of the capacitor indicating the side with the negative lead. For a cylinder-shaped radial capacitor, the negative lead will also be shorter than the positive. This attention to polarity is necessary since if electrolytics are inserted backwards, they can rupture or even explode.

The left-most toggle switch allows you to switch between C1 and C2. Since C2 is larger than C1 by a factor of 1,000, switching from C1 to C2 will lower the clock frequency by the same factor. Thus C1 selects the high-frequency range ⎍⎍⎍, and C2 selects the low-frequency range ⎍⎍⎍. With C1 in the circuit, the frequency will be approximately 1,000 Hz (1 KHz), while with C2, the frequency will be around 1 Hz. The timer output will be used to clock a counter chip (the 7493) and D and JK flipflop chips (7474 and 7476).
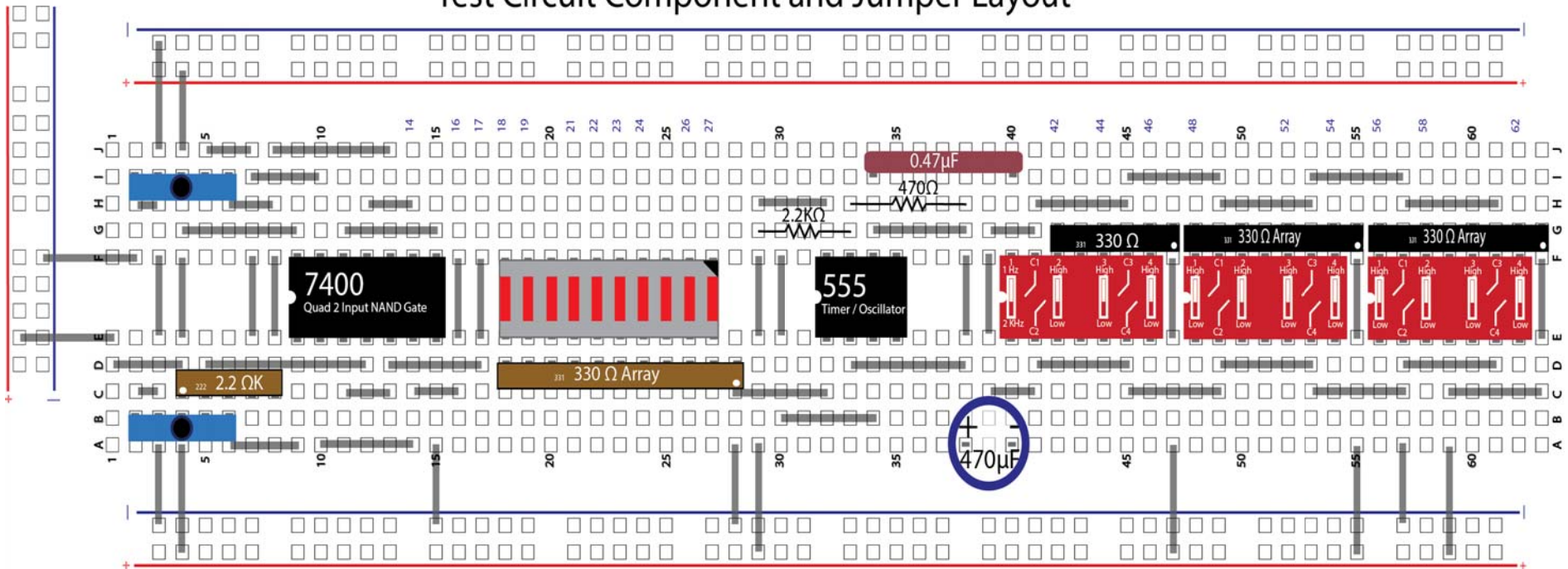
See photo and discussion on pg.7.

The high frequency clock (using C1) is provided for testing circuits with a scope. Its period is about 1 msec (1/1000 sec) which corresponds to one horizontal division on the scope screen when using the 1 msec/cm setting. Don't try to display high-frequency voltage changes using LEDs; the changes are too fast for the eye to see. In contrast, display low-frequency voltage changes (using C2) with the LEDs rather than the scope.
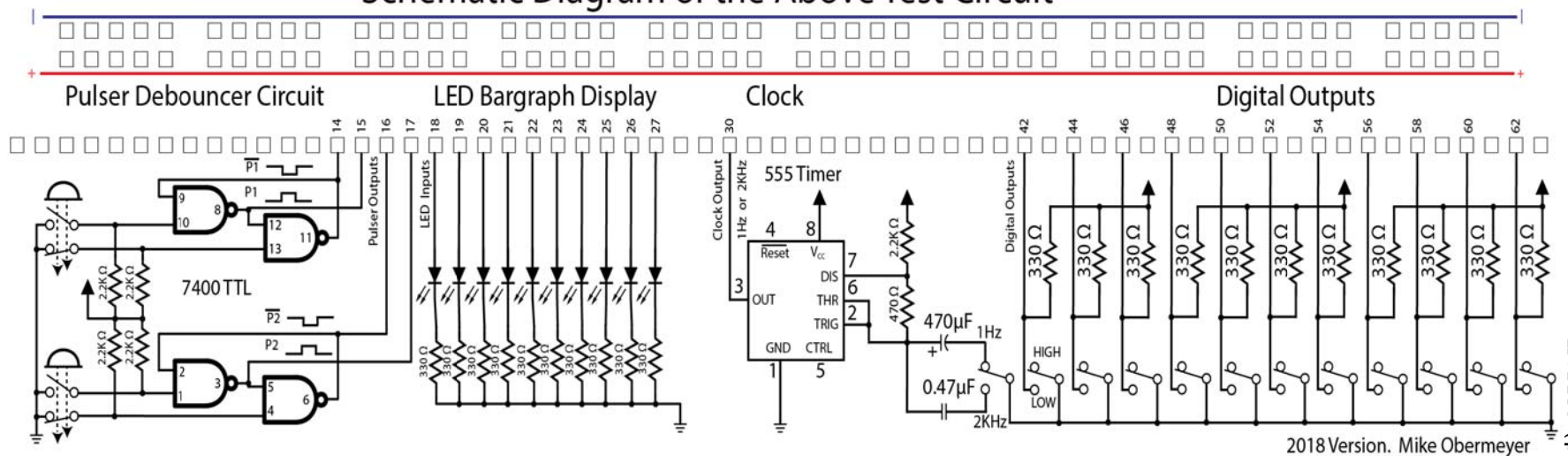
Also, when trouble-shooting a circuit that is not working properly, it is usually better to disconnect the clock from the 555 timer and use a pulser instead. The problem with using the 555 clock is that you can't stop it when you want to freeze circuit operation so you can check for connection errors with a logic probe.

4.   TOGGLE (DIP) SWITCHES--to the right of the toggle switch that selects between C1 and C2, there are 11 more toggle switches. Switch outputs are found in the holes so marked on the layout diagram. Each output is adjacent to a 330Ω pull-up resistor. When a switch is open (up), its output voltage is "pulled up" to 5V by the resistor. (With the switch open, no current flows through the resistor, so the voltage at its lower end is the same as at its upper end; i.e. 5V.) When the switch is closed (down), it connects the lower end of the resistor to ground, so the switch output voltage falls to 0V. (Circuit diagram for dip switches is at the end of this Intro section.)

Test Circuit Component and Jumper Layout

7400 — Quad 2 Input NAND Gate

555 — Timer / Oscillator

0.47µF

470Ω

2.2KΩ

2.2 ΩK

330 Ω

330 Ω Array

470µF

330 Ω Array

330 Ω Array

1 Hz / 2 KHz / High / Low / C1 C2 C3 C4

Schematic Diagram of the Above Test Circuit

Pulser Debouncer Circuit

P1 P1
P2 P2
Pulser Outputs
7400 TTL
2.2K Ω

LED Bargraph Display

LED Inputs
330 Ω

Clock

Clock Output
1Hz or 2KHz
555 Timer
Reset Vcc
OUT DIS
THR
TRIG
GND CTRL
4 8
3 7
6
2
1 5
2.2K Ω
470µF 1Hz
0.47µF 2KHz

**Digital Outputs**

Digital Outputs
330 Ω
HIGH
LOW

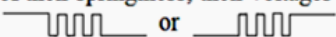2018 Version. Mike Obermeyer

Link to Illustrator file of this diagram

The photo at the right is of the RC timer cicuit. The 555 timer is the 8-pin chip in the middle. Its output is at row 30 (circled).

The large radial electrolytic capacitor is C2 with a value of 470µF; the elongated brown ceramic capacitor parallel to and above the 555 is C1 with a much smaller value of 0.47µF.

The switch nearest the capacitors is used to connect one of them to the 555 timer circuit.. It connects the capacitor that it points *away from*, which, in this case, is C1.
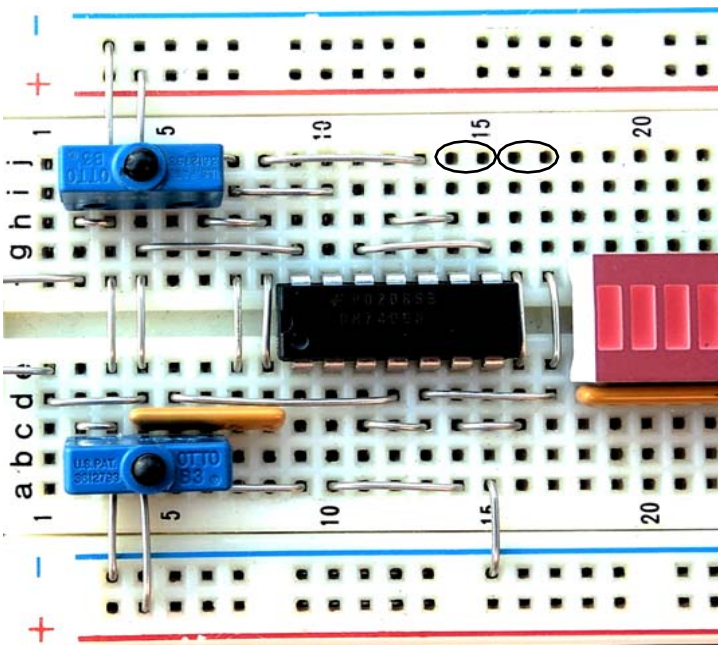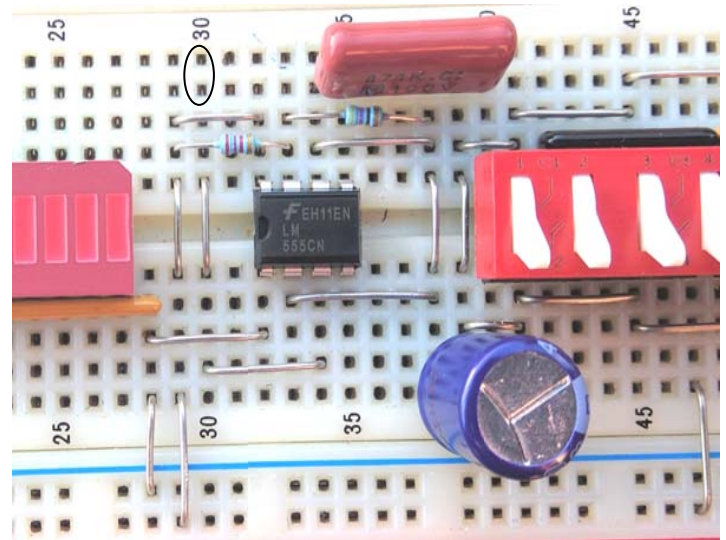
The photo at the left is of the two pulsers (push-button switches) and the 7400 NAND chip that debounces their outputs.These outputs (also shown in the diagram on the previous page) are circled: the two holes at rows 14 and 15 are debounced outputs of the top pulser; those at rows 16 and 17 are of the lower pulser. (Each pair consists of a normally high and a normally low output.)

When a pulser is pressed, its metal contacts come together and, because of their springiness, their voltages initially "bounce", as shown: ⎺⎺⎽⎾⎿⎾⎿⎾⎿⎽⎽ or ⎽⎽⎽⎾⎿⎾⎿⎾⎿⎺⎺

Because of this behavior, the direct output of the pulsers can't be used to clock a counter or flipflop chip since one press of a pulser results in many pulses (more than shown here). So the outputs are brought to a 4-NAND 7400 chip. The gates are connected as two latches. As soon as a pulser output changes level, the latch output flips accordingly and the bounces that follow are ignored:
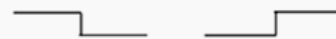

D: USING TOOLS:

1. **Wire Cutter/Stripper**: it will take a bit of practice to get used to using this tool to strip the ends of wire, especially with short pieces. It is important to remember not to strip off too little or too much and not to bite through the insulation into the wire itself. The bare wire end after stripping should be about 1/4" long.

☐ If it is too long, there is a chance that once you insert it into a hole on your breadboard, it might curl up underneath and make contact with a different hole, possibly shorting two conductors together.

☐ If it is too short, you might push some insulation into the hole. If the insulation but not the wire contacts the metal in the hole, you will have the appearance of a connection but, in reality, no connection at all.

Some wire strippers have an adjustable screw which allows you to set the size of the wire to be stripped. Because the screw may not remain properly adjusted, or because you have to change adjustments as you change wire, you may wish to gauge wire size by "feel" instead. While you are learning how to do this, try to avoid cutting through the insulation into the wire itself.

If you cut the wire, but not so deeply as to cut off the end, the end can still break off later once you have inserted it into a hole. This can result from just a small movement of the wire. Once a piece has broken off in a hole, it is difficult to remove. The result is usually a hole that can no longer be used.

      YES   NO   NO   NO
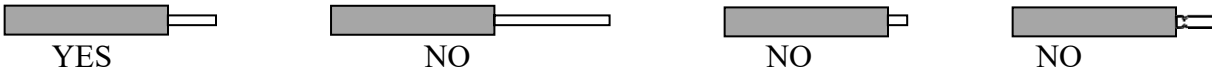
2. **Logic Probe**: this is the most important diagnostic tool you will have in this lab. Read the material in the next section--Implementing and Troubleshooting Designs--for a discussion of how to find and correct problems in your circuit using a probe. The logic probe contains two switches:

- TTL/CMOS: this switch selects between TTL and CMOS. You will be using TTL chips in the lab.

- MEM/NORMAL: If a voltage pulse occurs at the point you are probing, and pulse duration is relatively long ⎯⎯⌐⎯⎯⎺⎯⎯ then you will be able to see the probe's low- and high-LEDs go on and off, and so detect the occurrence of the pulse. No special indicator is needed, and the NORMAL setting is OK. But if the pulse is very short ⎯⎯⎯⎀⎯⎯ (say μseconds), then you won't be able to see the high-LED flash ON. This is where MEM (memory) is useful; it can record a pulse that is too fast to see and indicate its occurrence with a special LED. In the lab, switch to whichever setting you find useful.

3. **Small screwdriver** or tip of logic probe. Use when it is necessary to remove a chip from the board by *gently* levering up one end of the chip a bit, then repeat at the other end. Alternate until the chip pops out.

Don't try to lever it up completely from just one side or you will find bent pins when it comes out. Also, don't pull it up from one side by hand lest you find one or more pins embedded in your thumb (ouch).
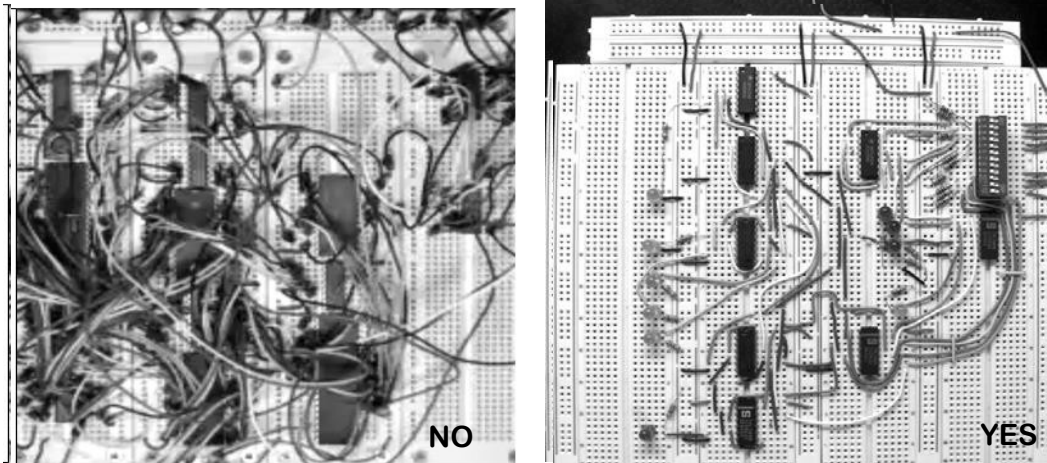
Therefore, when wiring up your circuit:

(1) you must leave space between chips so you can get a screwdriver in, and

(2) you can't have the chips covered over with wires, which would require removing the wires to get at the chip. Instead, lay the wires flat on the board and route them between and around the chips.
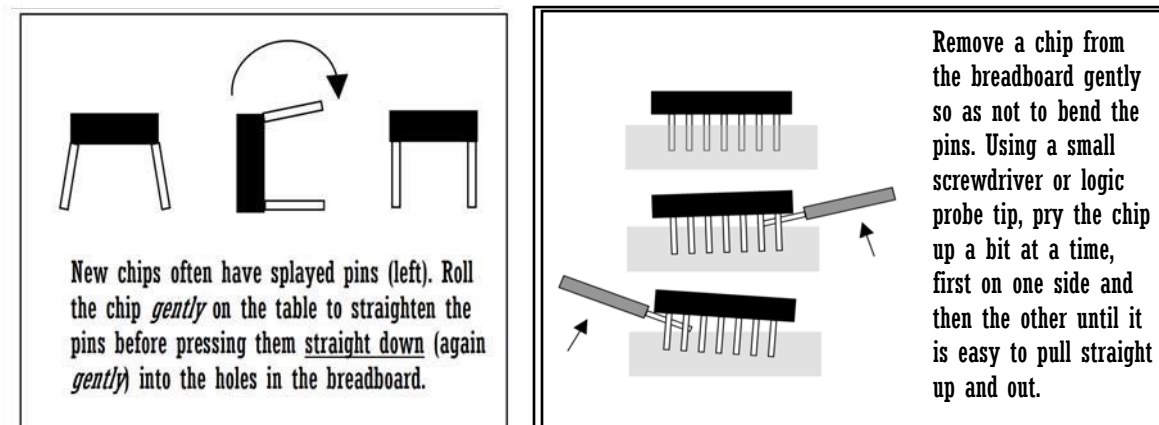
HINTS ON WIRING A CIRCUIT

There are many YouTube videos on breadboards. Here are two (you can access them by name or link):

☐ Introduction to Breadboard (Protoboard), Part 1 of 2: http://www.youtube.com/watch?v=oiqNaSPTI7w

☐ Breadboard Rules of Thumb: http://www.youtube.com/watch?v=Ebzh0utSu8I
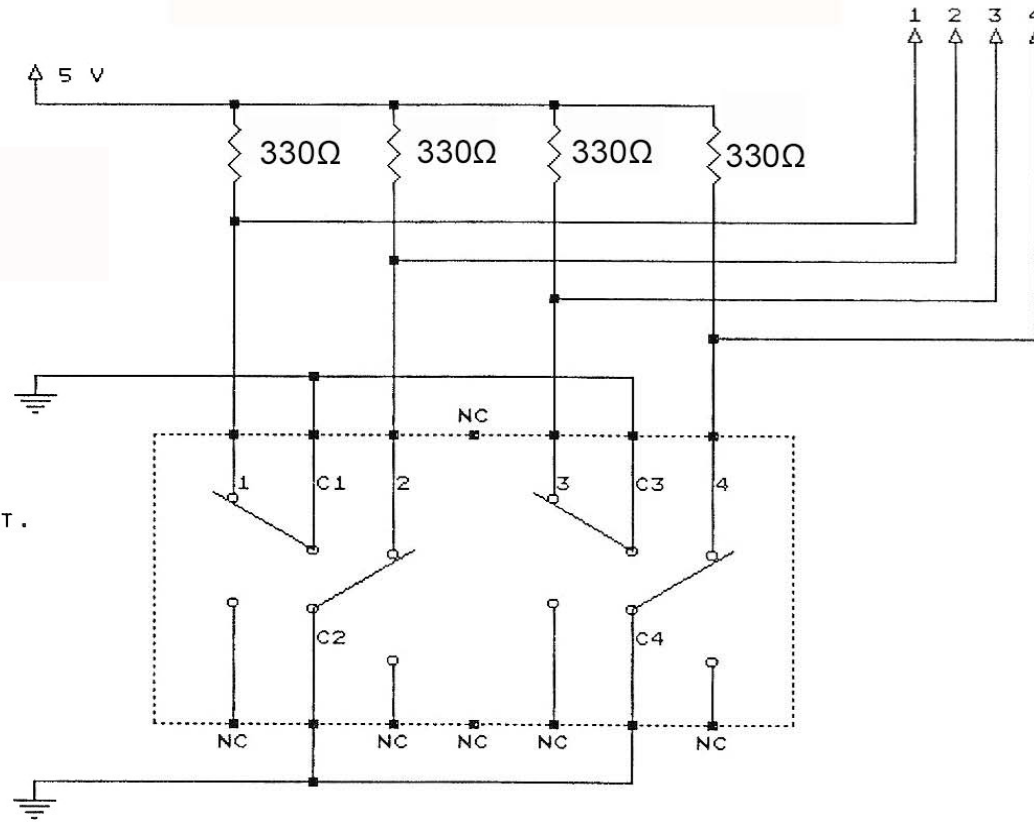

NO   YES

Above at the left is a perfect example of how *not* to wire up your circuit (it's referred to as "spaghetti" wiring).

- It is virtually impossible to trace the connections.
- It's impossible to remove a chip if it's bad without ripping out all the wires that cover it.

New chips often have splayed pins (left). Roll the chip *gently* on the table to straighten the pins before pressing them straight down (again *gently*) into the holes in the breadboard.

Remove a chip from the breadboard gently so as not to bend the pins. Using a small screwdriver or logic probe tip, pry the chip up a bit at a time, first on one side and then the other until it is easy to pull straight up and out.

Pulser Debouncer, ExpressSCH drawing

Pulser Debouncer, Illustrator drawing

Note: 330Ω values for pull-up resistors is approximate. 2.2KΩ is also OK.

5 V

330Ω   330Ω   330Ω   330Ω

1 2 3 4

OUTPUTS 5-8 FROM A SECOND QUAD DIP SWITCH CAN BE PLACED NEXT TO THESE FOUR.

NC

SWITCHES ARE USED AS SPST.

("NC" = NOT CONNECTED)

1   C1   2   3   C3   4

C2   C4

NC   NC   NC   NC   NC

OUTPUT = 0 V.

4

C4

NC

LOW

SWITCH PROFILE

OUTPUT = 5 V.

4

C4

NC

HIGH

SWITCH PROFILE