EXPERIMENT 13: LOGIC CIRCUITS 5/9/06

The purpose of this experiment is to gain some experience in the use of digital logic circuits. These circuits are used extensively in computers and in physics experiments.

The Integrated Circuits

All of the circuits we will use are members of the TTL logic family. The circuits are all integrated circuits (IC's) from the 74LS00 series, and are in the form of 14 pin dual in-line epoxy packages (DIPs).

1. The circuits operate from a single DC power supply of +4.75 volts. They can be destroyed if the supply voltage is raised above +5.5 volts or made negative even briefly. The logic levels are:
   4.75 V - logical ONE
   2.00 V - lowest voltage reliably recognized as logical ONE
   1.40 V - switching level
   0.80 V - highest voltage reliably recognized as logical ZERO
   0.00 V - logical ZERO

2. The delay in passing a signal through one NAND gate is typically 13 ns.

3. The output impedance is about 50 Ω.

4. The circuits can operate in air within the temperature range of 0-70°C.

Apparatus

All of the digital circuits needed for the next two laboratories have been incorporated into prewired "logic boards." The integrated circuits are mounted in DIP sockets inside the chassis of the logic board, with the inputs and outputs wired to external connectors. The +4.75 volt power supply is also located inside the chassis. The ground and DC power leads are permanently wired to the DIP sockets. The ground wire is large (22 gauge) to reduce its inductance and noise. The DC power line is bypassed to ground at several points by low-inductance disc ceramic capacitors. This reduces the spikes in the supply voltage caused by the rapid switching of currents in the circuits.

Each logic board contains the following circuits:

16	2-input NANDs	8	J—K flip flops
3	3-input NANDs	1	4 bit adder
10	indicator LEDs	1	UART
4	push button switches	4	toggle switches

Please note the following points:

1. Green connectors indicate outputs. To prevent damage by accidental shorting, a 47 Ω resistor has been placed in series with each output. The output can drive 4 inputs to logical ONE or ZERO.

2. Grey connectors indicate inputs. The inputs have a very non-linear impedance (2 kΩ near 0 volts and 20 kΩ near + 4 volts) and may be connected to any voltage between 0 and + 4.75 volts.

3. Light emitting diodes (LEDs) driven by buffer circuits can be used to indicate the digital voltage level at various points in the circuit:
   ON = logical ONE; OFF = logical ZERO.

4. Push buttons and switches can be used to provide logical ONE or logical ZERO inputs for other circuits on the board.

5. Any inputs that are left unconnected float high (logical ONE).

LABORATORY EXCERISES

Perform the exercises outlined below. As you go through the individual operations it should become apparent how the simple circuits can be combined to perform more complex operations. Do not introduce any external voltages into the circuit board.

1. Experimentally determine the truth table for a 2 input NAND.

2. Experimentally determine the truth table for a 3 input NAND.

3. Use 2-input NAND gates to construct circuits that perform the following logical functions. In each case draw the circuit diagram and experimentally determine the truth table.

   a) 2-input AND gate
      A AND B=$A \bullet B$

   b) 2-input OR gate
      A OR B = A+B

   c) 2-input NOR gate
      A NOR B = $\overline{A + B}$

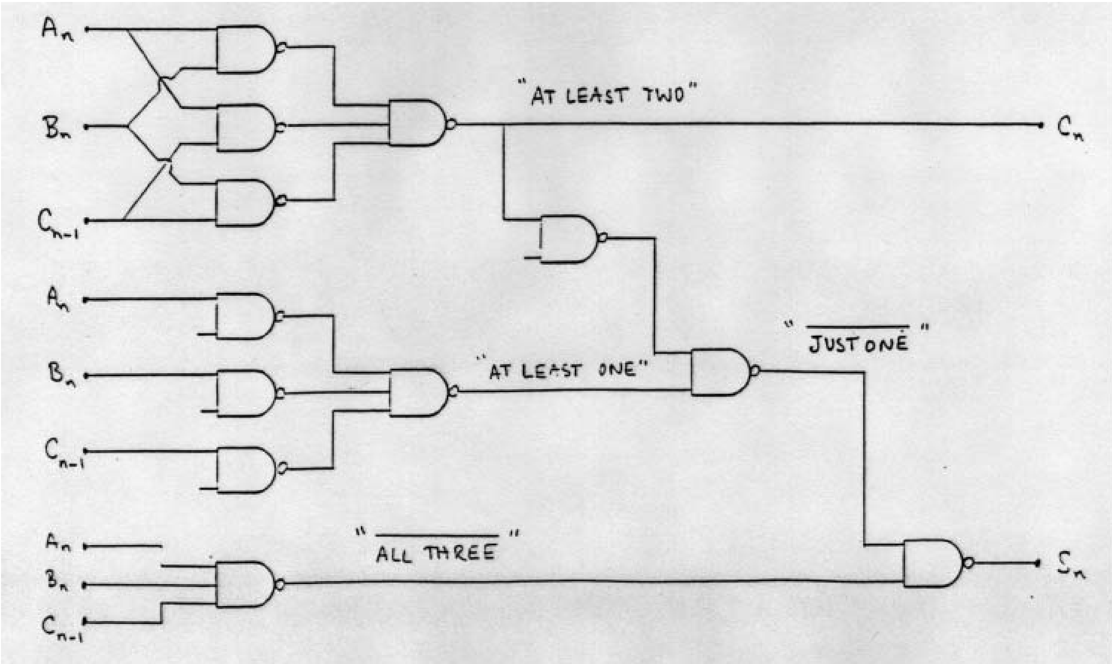
   d) 2-Input Exclusive OR
      $A \oplus B = A \cdot \overline{B} + \overline{A} \cdot B$

4. Use NAND gates to construct circuits that perform the following functions. In each case try to minimize the total number of gates, using 3-input NANDS wherever possible. Sketch your circuits and write out at least a portion of the truth table.

   a) $(A \bullet B) + C$
   b) $((A \bullet B) + C) \bullet D$
   c) $(A \bullet B) + (C \bullet D)$
   d) $(A \bullet B \bullet C) + D + E$

5. In this step we will construct a digital comparator. A comparator is a circuit that compares the values of 2 numbers (A and B) and gives a ONE if A = B and a ZERO if A and B are unequal. Assume that A and B are both 2-digit numbers. This means that your circuit will have 4 inputs (one for each bit of each number). Devise a circuit that carries out this operation, sketch the circuit diagram in your notebook and verify that the circuit does what you want. (Hint: The XOR circuit constructed in step 3(d) has some of the features of a 1-digit comparator. You need two such circuits, one for the first bit and another for the second bit.)

6. The circuit shown below is referred to as a full adder. This circuit can be used to add two numbers, A and B. The numbers are added one digit at a time starting from the least significant digit.



In each step we combine 3 inputs

- the nth bit from A $[A_n]$
- the nth bit from B $[B_n]$
- the carry bit from the previous step $[C_{n-1}]$;

and generate two outputs,

- the nth bit of the sum $[S_n]$
- a carry bit for the next step $[C_{n-1}]$.

Construct the full adder circuit and use it to add A = 14 and B = 11 (both base 10). Record in your notebook the steps you follow and the results you obtain.

7. The 4-bit adder on the logic board is a single chip that performs the function of 4 full-adder circuits like the one constructed in step 6. (Note that the carry input and the carry output allow one to connect N of these chips toobtain a 4 x N bit adder). Use the 4-bit adder to add the following pairs of numbers:

a) 6+7

b) 13 + 5

c) 11 + 14

Next try using the adder to add signed numbers. Since we are using 4-bit words we can only represent 16 different numbers, so we will restrict ourselves to the range –8 to +7. Add the following pairs of numbers:

a) (–3) + 5

b) 3+ (–5)

c) (–2) + (–3)

You will need to use the twos-complement scheme (e.g. –3 = 1101) to represent the negative numbers. observe what happens if you just try to use the left-most bit to indicate the sign (i.e. –3 = 1011).