

## LABORATORY SUMMARY

These laboratory exercises focus on the design and implementation of canonical logic equations to control a mobile robot. The equations become the computer brain of the robot and allow the robot to complete tasks. The robot consists of a plexiglass body, two bidirectional motors, three line sensors, a collision sensor, and a prototype breadboard used to interconnect integrated circuit chips (ICs) to implement logic equations. The line sensors are mounted under the body and point down toward the ground. The collision sensor is mounted on the front of the body and points ahead of the robot.

Students will complete three design tasks:

- **Design** canonical equations for a line-following robot.
- **Redesign** the equations using an input set that reduces equation size.
- **Implement** the redesigned equations using standard logic integrated circuit chips.

The laboratory exercises reinforce these CE1900 learning objectives:

- **Design** canonical equations from a truth table.
- **Implement** canonical equations using standard 7400 family logic chips.
- **Use** datasheets to aid in circuit construction and timing analysis.

**Print** this document and **bring** it to lab with the preliminary activities completed in the spaces provided. **Hint:** save your color print cartridge by selecting “black-and-white” printing from your print options.

## REMEMBER

**Complete** all preliminary lab exercises *before you come to lab*.

**Review** the in-class laboratory exercises to preview the work you will do in the lab.



# CE1900 WEEK 2 LABORATORY EXERCISES

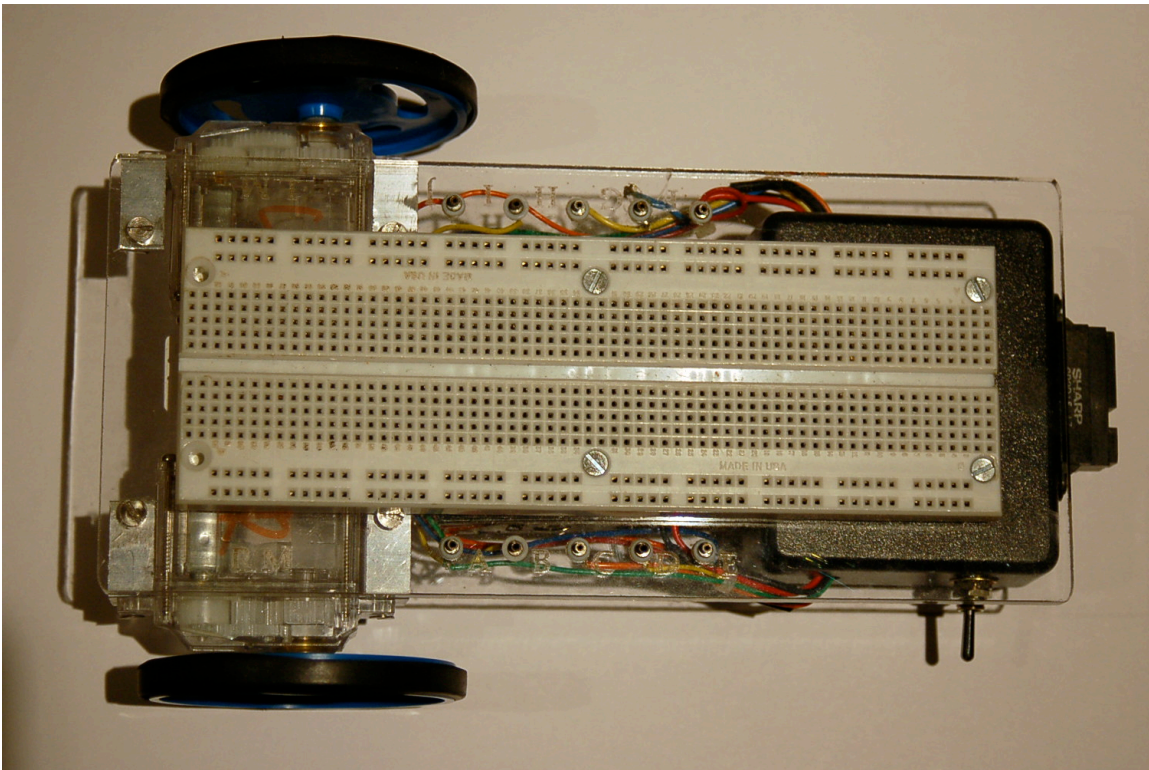
## PRACTICE PROBLEMS

**Test** your progress in meeting your course learning objectives by completing these practice problems. Practice problems are for your personal study and may be collected and checked as part of your overall lab grade. **Ask** your instructor for help if needed.

1. **Derive** the canonical logic equation for a three-bit less-than-4 detector.  
**Mathematically**,  $G(ABC) = 1$  if and only if  $ABC < 4$ .
2. **Determine** the number of logic gates in the canonical logic equation for a 4-bit multiple-of-5 detector. **Mathematically**,  $M5(ABCD) = 1$  if and only if  $ABCD = 5 * n$  for  $n = 0, 1, 2$ , and so on.
3. **Derive** the canonical logic equation for a component that monitors 4 input bits called A, B, C, and D and produces a 1 if exactly three of the inputs are equal to 1. Use the Quartus software to **draw** and **simulate** your blueprint.
4. **Derive** the canonical logic equation for a component that monitors 4 input bits called I, J, K, and L and produces a 1 if and only if IJKL is divisible-by-6. Use the Quartus software to **draw** and **simulate** your blueprint. **Yes**, zero is divisible by 6 because  $0/6 = 0$ .

## PRELIMINARY LAB READING: THE ROBOT COMPONENTS

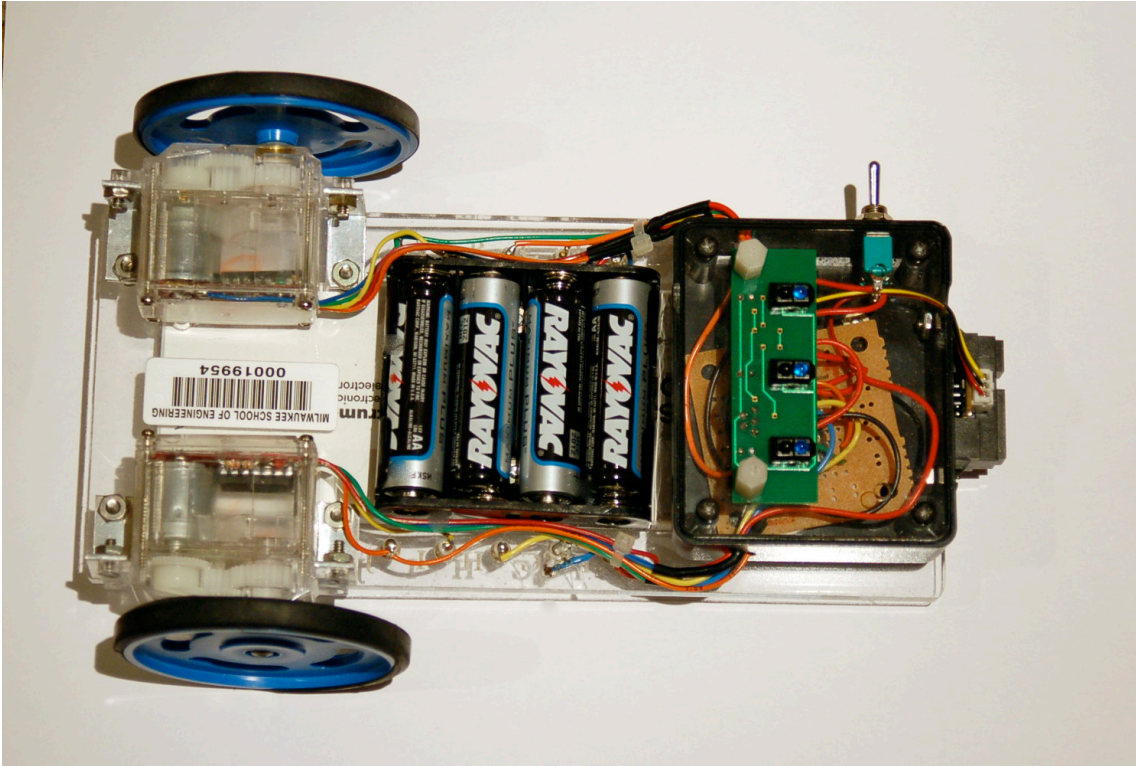
The laboratory robot is shown in Figure 1. Note the DC motors and wheels mounted on the rear of the robot and the collision sensor on the front of the robot. The toggle switch is used to apply battery power to the robot components. The central white plugboard (also called a breadboard) is used to interconnect integrated circuit chips to each other and to the robot sensor and motor signals. The sensor, motor, and power supply signals terminate at metal wire connection plugs along each side of the robot's plexiglass body. Although they are difficult to see in this photograph, the wire connection plugs are named and the name of each is etched into the plexiglass.



**Figure 1: Top View of the Laboratory Robot**

A bottom view of the laboratory robot is shown in Figure 2. The robot sensors and motors operate from standard digital logic voltages, 0V and 5V. Thus, four (4) AA batteries are placed in series (end-to-end: + to - to + to - etc.) to generate a 6V power supply. Each AA battery produces 1.5V and a series connection sums the battery voltages ( $1.5+1.5+1.5+1.5 = 6V$ ). A **voltage regulator** component inside the robot reduces the power from 6V to 5V for use by the robot components. Note the motors, the battery compartment, and the line tracker component with three infrared line sensors just to the

right. Each infrared sensor is actually an infrared transmitter and receiver pair. Infrared energy is transmitted down toward the ground from each infrared transmitter. Surfaces reflect infrared energy similarly to the reflection of visible light energy. Thus, each infrared sensor will see a reflection of the energy it transmitted if that sensor is over a light colored surface. If the sensor was over a dark surface it will not see a reflection.



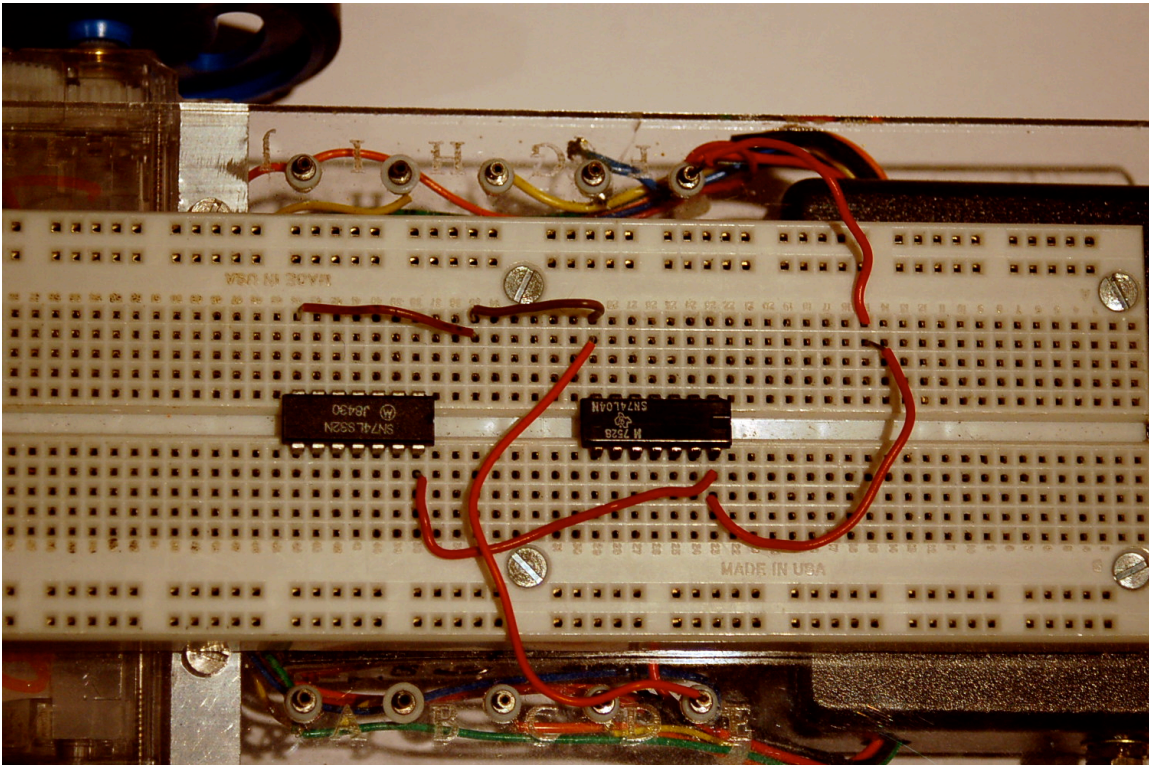
**Figure 2: Bottom View of the Laboratory Robot**

Figure 3 demonstrates integrated circuit chips correctly inserted into the plugboard. The plugboard is divided into two halves – a top half and a bottom half. Each half is lettered lightly on the surface of the plastic with a name. The top half is lettered as the “A” half and the bottom half is lettered as the “B” half. It is easy to see that the halves are isolated from each other by a depression in the plastic – the chip gap. Each half contains sixty-four (64) columns. Each column consists of five plug points. Each column is a unique connection node for wires and chip pins. Any wire or pin plugged into the same column is electrically connected to everything else plugged into that column. Each plug point in a column supports only one pin or wire.

Integrated circuit chips encase a microscopic electric circuit in plastic or ceramic. Industrial robots wire the internal electrical input and output signals from the microscopic



circuit to metal pins on the surface of the chip during fabrication. The body of an IC sits across the chip gap with each pin plugged into a column of the plugboard. Thus, each input and output signal of the chip has its own unique connection point! This explains why the plugboard has two halves. The “A” half handles the pins on one side of the chip and the “B” half handles the pins on the other side of the chip. Chips are inserted in the plugboard by carefully bending and aligning the pins and then gently pushing downward until the chip pops into the board. Chips are removed from the plugboard by using a chip remover – a special tool that can be purchased – or by using the index fingers and thumbs on opposite long sides of the chip to gently rock it back and forth across the chip gap.



**Figure 3: Integrated Circuit Chips (ICs) Inserted in the Pegboard**

The challenge is to remove the chip *without* bending the pins, or worse, breaking them off in the plugboard.

Figure 3 also demonstrates wires connected between columns. Some of the wires connect pins of the ICs while other wires bring robot signals to the IC chips. Note that the rightmost pins of each chip in the “B” half are connected with a single wire between the columns. The rightmost pins are also connected to signal F of the robot with wires. The “F” signal name can be seen in the upper right hand corner of the robot etched into the



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plastic – although it is very faint in the photograph. Note that the leftmost pins of each chip in the “A” half are connected. Two shorter wires were used to “jump” between the chips and an intermediate column not connected to any other chip pin was needed to accommodate the shorter wire lengths. The leftmost pins are also wired to the robot signal named E.

## KEY POINTS

Wiring is a skill that comes with practice. Remember these key points:

- each column is the *same* connection node
- a plug point supports only one wire or pin
- use intermediate columns to jump multiple wires if needed to finish a connection
- use shorter wires and keep the wiring tight against the board

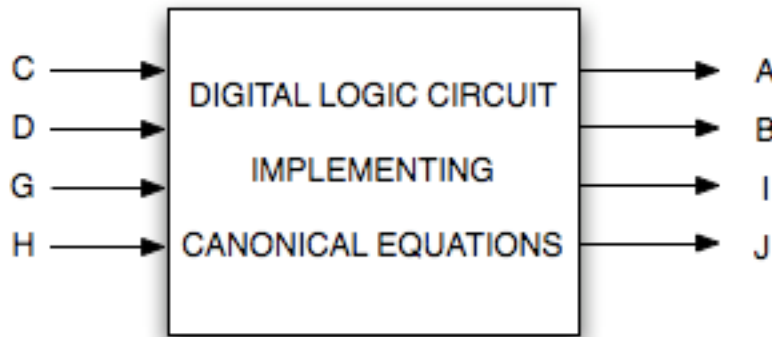
## PRELIMINARY LAB READING: THE ROBOT ELECTRICAL SIGNALS

The robot input and output signals are summarized in Table 1. Note that the battery power terminals are called VCC (+5V) and GND (0V). In circuit theory, ground (GND) represents the return path for current returning from the circuit to the power supply – hence the negative terminal of the battery.

**Table 1: Robot Electrical Signals**

NAME	TYPE	MEANING	IF 0	IF 1
<b>A</b>	Control	Right motor direction	reverse	forward
<b>B</b>	Control	Right motor on/off	off	on
<b>C</b>	Sensor	Right line sensor	over black	over white
<b>D</b>	Sensor	Collision sensor	no collision	collision
<b>E</b>	Power: GND	Battery negative (0V)		
<b>F</b>	Power: VCC	Battery positive (+5V)		
<b>G</b>	Sensor	Center line sensor	over black	over white
<b>H</b>	Sensor	Left line sensor	over black	over white
<b>I</b>	Control	Left motor on/off	off	on
<b>J</b>	Control	Left motor direction	reverse	forward

A robot brain can be created with these signals. Each robot sensor (C, D, G, and H) is a digital signal that becomes an **input** to a circuit that implements canonical logic equations you have designed to control the robot behavior. A canonical logic equation would be needed for each control signal A, B, I, and J. Figure 4 illustrates this equation mapping in block diagram form.



**Figure 4: Block Diagram of Design Problem**

Each sensor input signal becomes one column of a binary number in a sixteen-row truth table used to design the output control equations. Note that not every robot behavior demands that every signal be used as input. Similarly, not every output signal may be needed for basic behavioral control. For example, an engineer could decide to always turn on the motors when the robot is powered and control only the forward or reverse motor direction. In this case, the engineer would wire robot signals B and I to the battery power supply (logic 1 = VCC = +5V) and only implement canonical equations for direction control signals A and J. Similarly, some task set might not depend on collision avoidance and thus sensor signal D could be ignored. In this case, the number of truth table rows decreases from sixteen to eight – reducing the complexity of the canonical equations. The block diagram under these simplifications is shown in Figure 5.

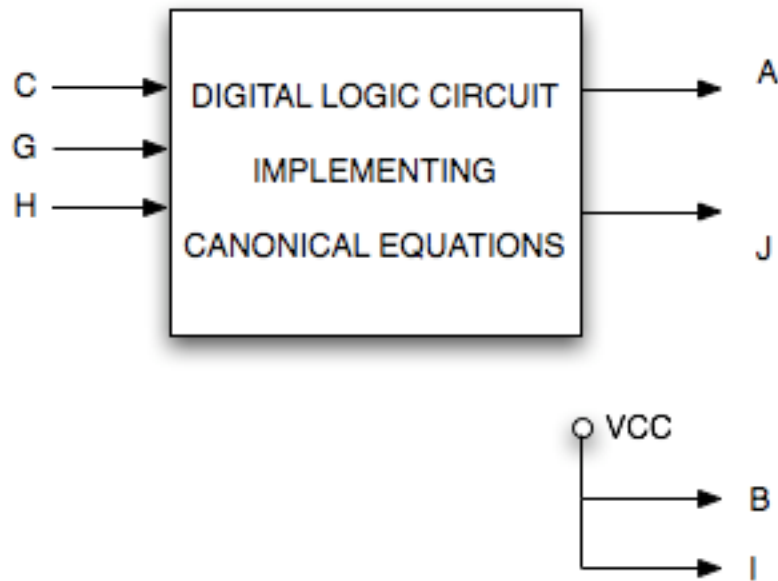


Figure 5: A Block Diagram with Reduced Signal Set

### KEY POINTS

Remember these key points about the robot signals:

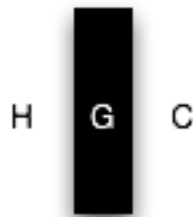
- motor forward = logic 1 = +5V
- motor reverse = logic 0 = 0V
- motor on = logic 1 = +5V
- motor off = logic 0 = 0V
- collision! = logic 1 = +5V
- no collision = logic 0 = 0V
- line sensor over white = logic 1 = +5V
- line sensor over black = logic 0 = 0V



## PRELIMINARY LAB EXERCISES

Each student must complete these exercises during study time.

1. **Complete** this truth table for the reduced block diagram shown in Figure 5. The task is to keep the robot centered over a black line of electrical tape placed on a white surface in a random path. The robot will be placed onto the track with the center sensor aligned over the black line in the direction of travel. Speed bumps have been taped onto the track at periodic intervals. The first step in design is to determine appropriate behaviors for each input pattern. The CE1900 instructors have made decisions about the behavior for this first exercise. **Complete** the output control table by writing appropriate voltages in each row based on the input sensor voltages. **Do not change** the behaviors chosen by the instructors.



Normal Track with Centered Robot



Robot Over a Speed Bump

INPUT SIGNALS			OUTPUT SIGNALS		
LEFT LINE SENSOR	CENTER LINE SENSOR	RIGHT LINE SENSOR	LEFT MOTOR DIRECTION	RIGHT MOTOR DIRECTION	BEHAVIOR
H	G	C	J	A	
0	0	0	1	1	forward
0	0	1			turn left
0	1	0			forward
0	1	1			turn left
1	0	0			turn right
1	0	1			forward
1	1	0	1	0	turn right
1	1	1			turn right



## CE1900 WEEK 2 LABORATORY EXERCISES

2. **Derive** the canonical sum-of-products equation for  $J = F(H,G,C)$  from the table:

J =

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3. **Derive** the canonical sum-of-products equation for  $A = F(H,G,C)$  from the table:

A =

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4. **Draw** the circuit blueprint diagram for signal J using logic gate symbols. **Assume** ideal logic gates. In other words, the gate can have an infinite number of inputs and the gate can energize an infinite number of wires connected to its output.



## CE1900 WEEK 2 LABORATORY EXERCISES

5. **Draw** the circuit diagram for signal A using logic gate symbols. **Assume** ideal logic gates. In other words, the gate can have an infinite number of inputs and the gate can energize an infinite number of wires connected to its output.

6. **Complete** this summary table about the circuits for equations J and A.

CIRCUIT	NUMBER OF GATES	NUMBER OF WIRES
J		
A	9	

7. **Redesign** the robot brain for the same task. This time, use only the left and right line sensors. In other words, the brain will ignore the energy on the center line sensor. This reduces the number of truth table rows from eight to four. **Remember** to fill in the behavior column first. **Don't change** any instructor provided behavior. **Remember:** the line sensor returns logic 0 (0V) if it is over the black line and logic 1 (5V) if it is over the white surface.



Normal Track with Centered Robot



Robot Over a Speed Bump

INPUT SIGNALS		OUTPUT SIGNALS		
LEFT LINE SENSOR	RIGHT LINE SENSOR	LEFT MOTOR DIRECTION	RIGHT MOTOR DIRECTION	BEHAVIOR
H	C	J	A	
0	0			reverse
0	1			
1	0			
1	1			forward



## CE1900 WEEK 2 LABORATORY EXERCISES

Canonical equations:

$J =$

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$A =$

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- Draw** the circuit diagram for the redesigned signal  $J$  using logic gate symbols. **Assume** ideal logic gates. In other words, the gate can have an infinite number of inputs and the gate can energize an infinite number of wires connected to its output.
  
- Draw** the circuit diagram for the redesigned signal  $A$  using logic gate symbols. **Assume** ideal logic gates. In other words, the gate can have an infinite number of inputs and the gate can energize an infinite number of wires connected to its output.





# CE1900 WEEK 2 LABORATORY EXERCISES

10. Complete this summary table about the circuits for equations J and A.

CIRCUIT	NUMBER OF GATES	NUMBER OF WIRES
J	4	
A		

*These circuits are much smaller than the original design and illustrate how design choices change the complexity of the final product.*

The remainder of this document consists of laboratory exercises that must be completed and demonstrated to the instructor during the laboratory period. **Read** through these exercises now to get a sense of the laboratory requirements.

## LABORATORY EXERCISES

Each student must complete exercise 1. A team of two students must complete the remaining exercises and demonstrate to the instructor during the week 2 laboratory period.

1. **Take** the weekly CE1900 quiz given by your instructor at the start of lab.
2. **Check** out the following items from the EECS Technical Support Center (S-348).

ITEM	QUANTITY
Digi-bot	1
Digital wire kit (blue box)	1
AA batteries	4
74LS04 NOT gate IC	1
74LS08 quad 2-input AND-gate IC	1
74LS32 quad 2-input OR-gate IC	1

3. **Review** the 7404 datasheet located on the CE1900 course webpage: (<http://faculty-web.msoe.edu/meier/ce1900>).
  - a. **Focus** on the pin diagram on page 1. **Key points** include:

- i. The depressed notch or dot in the top of the chip helps you identify pin 1 – it is always to the left of this notch or dot.
    - ii. Pin numbers always advance counterclockwise around the chip.
    - iii. 7400 family logic chips always have battery ground (GND) at the lower left and battery positive (VCC) at the upper right.
    - iv. Datasheets often show the commercial family (7400) and military-grade family (5400) pin diagrams.
  - b. **Focus** on the logic diagram on page 3.
  - c. **Note** that datasheets typically provide tables of electrical specifications as shown on pages 5-7. Some of these specifications will be discussed in CE1900 and others will be learned in later courses.
  - d. **Note** that datasheets typically provide diagrams of the internal electronic circuit as shown on page 4. This material is very advanced and will not be covered in CE1900.
4. **Review** the 7408 and 7432 datasheets located on the CE1900 course webpage. **Focus** on the pin diagrams and logic diagrams.
5. **Build** the reduced logic equations you designed in pre-lab exercises 7-10 using the Digi-bot protoboard, the 7400 family chips, and the wires from the wire kit. **Build** the canonical circuits. **You are not allowed to use Boolean algebra or K-maps to further reduce the circuits.**
- a. **Remember** that each chip *must* be connected to the battery VCC and GND because the internal circuit must have energy for doing work. **Use** the VCC and GND pins on the chip and the VCC and GND signals from the robot. **Refer** to Table 1 in this document for robot signal names.
  - b. **Remember** that the design choices made in this document always had the motors on when the robot was powered. **Don't forget** to wire robot signals B and I – the motor on/off signals – to VCC as shown in Figure 5.
  - c. **Remember** that the design choices ignored the center line sensor and the collision sensor. **Do not** wire these robot signals to any chip because they aren't used!
6. **Test** your robot on the track provided in the laboratory room. **Debug** your wiring by carefully checking every connection if the robot fails to meet the requirement of line following.
7. **Demonstrate** your robot to the instructor. The instructor will complete the signature block at the end of this document. The signature block serves as proof



## CE1900 WEEK 2 LABORATORY EXERCISES

that you have completed the laboratory assignments. **Keep** this document in your binder for CE1900 in case you need to refer to it in future work or in case the instructor asks to see the signature block again at a later date.

**FOR INSTRUCTOR USE ONLY: DO NOT WRITE IN THIS TABLE**

ITEM	COMPLETED	SCORE
Prelab Exercises		
Demonstrates understanding of datasheet material		
Robot demonstration		

Instructor Signature: \_\_\_\_\_