Experiment 1
Introduction to Digital Lab Equipment

1. Purpose

To get familiar with the CADET logic station and HP54654 Oscilloscope/Logic Analyzer used in this lab.

2. Prelab

Read "Tips on wiring" (documents in class website).

3. Reference

*Use and Service of HP54645A Oscilloscope and HP54645D Mixed Signal Oscilloscope.*

4. Discussion

4.1. C.A.D.E.T logic design station

"CADET" is a logic design station that consists of a breadboard and a collection of circuits that facilitate the implementation and testing of digital circuits. The circuits include a power supply, a simple function generator, regular and de-bounced switches, and logic indicators (red and green LEDs). In our lab, the functional generator is normally used to generate required square wave, which is used as the clock signal of sequential circuit. The switches are used as input signals and the logic indicators are used to monitor signal's logic level (High or Low).

The breadboard is designed for both CMOS and TTL devices, which are operated in different voltage ranges. We are using TTL devices in this lab, and thus all selection should be set to TTL or 5V position.

4.2. HP 54645D oscilloscope/logic analyzer

HP 54645D is the major testing equipment used in this lab. It essentially combines two testing facilities in one unit to measure both analog and discrete signals (thus named as mixed-signal oscilloscope). It functions as a regular analog oscilloscope, similar to the one used in your Electronic Lab, as well as a logic analyzer. A logic analyzer is primarily used to examine digital circuit. It displays signal waveform and relevant timing information, as in an analog oscilloscope. However, unlike an oscilloscope, the signal amplitude is represented in two discrete levels rather in a continuous format. A representative display of an oscilloscope and a logic analyzer of a signal is shown below:
Clearly, an analog oscilloscope can always provide more information. However, the circuitry to obtain and process continuous waveform is quite complex, and thus an oscilloscope is normally limited to two to four channels. On the other hand, the circuitry to digitize a signal much simpler and a logic analyzer normally contains 16 to 64 channels. HP54645D contains two analog channels (as an oscilloscope) and 16 digital channels (as a logic analyzer).

4.3. Miscellaneous equipment

Each group also has a DMM and a logic probe. The logic probe is a handy tool to check logic level. Remember to connect its power and ground to CADET.

5. Components

74LS00, 74LS163, two 10K Ω and one 330 Ω resistors.
6. Procedures

6.1. Voltage level of LED indicator
(a). Check CADET to make sure that all selection switches are set in TTL or 5V positions.
(b). Measure the output voltage of switch $S_1$. It should be either 0V or 5V.
(c). Connect the output to a logic indicator. The green LED will be on when the switch output is 0V and the red one will be on when the output is 5V.
(d). The logic indicator has two voltage thresholds, one for logic 0 and one for logic 1. The green LED is on when the input voltage is lower than the threshold of logic 0. The red LED is on when the input voltage is higher than the threshold of logic 1. Both LEDs are off if the input voltage is between the two thresholds. Regular TTL output should be either logic 0 or logic 1, and thus one of the LEDs is always on. However, when two TTL outputs are shortcircuited (a wiring error), the resulting voltage may lie between the two thresholds and no LED is on. Thus, you need to check your wiring when both LEDs are off.
(e). Following circuit is used to determine the two thresholds of logic indicator. Use the 10K pot of CADET to implement this circuit and record the results. [Diagram]

6.2. Basic combinational logic gate
(a). Use one 74LS00. Connect the $V_{cc}$ and Gnd following the rules and procedure of section 4.5.
(b). Choose a NAND gate. Connect the two inputs to two switches (say $S_1$ and $S_2$) and the output to an LED indicator. Try all four possible input combinations and verify the operation of the NAND gate.
(c). Implement the following circuit using three NAND gates (Note that the connection of $V_{cc}$ and Gnd are normally not shown). Use 4 switches as inputs. Go through all 16 possible input combinations and observe the output. List the results as a truth table. [Diagram]

6.3. CADET function generator
(a). Connect A1 channel of oscilloscope to the TTL socket of CADET’s function generator. Observe the waveform on oscilloscope. Adjust the amplitude and frequency control of the function generator, and observe the change in waveform.
(b). Connect A2 channel of oscilloscope to the square wave socket of CADET’s function generator. Observe both input channels. Adjust the amplitude and frequency control of the
function generator, and observe the change in waveforms. Set the function generator to 10K Hz and record both waveforms. (R)

6.4. Basic counter
(a). Use one 74LS163 to implement the following circuit. It is known as “free-running” mode of 74163, which is a mod-16 counter. Note that all unused control signals are connected to a logic source to avoid floating input, as discussed in section 4.4.

![Diagram of 74LS163 circuit](image)

(b). Connect outputs Qd, Qc, Qb and Qa (in which Qd is MSB) as well as Rco of 74163 to 5 LED indicators and connect input clock to TTL socket of functional generator. Set frequency of function generator to about 1 Hz. Observe the counting sequence in LED indicator and record counter output (staring with all 0) for 20 clock pulses. (R)

6.5. Bounces in a mechanical switch
(a). All switches of CADET, except PB1 and PB2, are regular mechanical switches. When we move a switch from one position to another, the contact of the switch springs back and forth for a while and then settles down. Thus, the transition from one voltage level to another usually contains several pulses, which are known as bounces.

(b). The bounces can be captured on oscilloscope by using proper trigger procedure:
- Connect a switch (say Sx) to channel A1.
- Press Edge button on oscilloscope and then choose A1 and positive edge in soft menu.
- Press Mode button on oscilloscope and then choose Normal in soft menu.
- Adjust Analog Level knob to 2V.
- Make sure that Sx is in low position.
- Press Single button on oscilloscope.
- Switch Sx from low to high and the transition should be captured and displayed.
- Expand the time base to observe the transition in detail. You may need to use delayed mode of oscilloscope to do this. Draw the waveform and record the oscilloscope setting. (R C)

(c). Repeat part (b) for few times, and also try different switches.
(d). Connect clock of 74163 of section 6.4 to a switch. We use it as a counter to measure how many bounces occurred in a transition. This can be done by observing the output in LED indicators. Make 10 switch transitions (i.e., 5 high-to-low moves and 5 low-to-high moves) and record the bounces in each transition. (R)

6.6. Debounced switch
(a). The two push-button switches PB1 and PB2 of CADET have some extra circuit to remove bounces (so they are “debounced” switches). The output of PB1 and PB2 switches between ground and open-circuit. They can be modeled as an ideal switch (i.e., no bounces). To use it, we need an external “pull-up” resistor to make them switch between ground and 5V. The output of debounced switch is clean. It is frequently used as a manual clock for sequential circuit. The pull-up circuit is shown below:

This drawing should be with the wiper contact grounded and the 10K resistor connected to the N.C. contact.

(b). Implement the circuit. Connect the output to channel A1. Use procedure in section 6.5(b) to capture the transition.

(c). Determine the rise time (i.e., from 0.1*Vcc to 0.9*Vcc) of the transition.

(d). Connect clock of 74163 to the debounced output. Push the button several times and observe the counter output in LED indicators.

(e). Implement the circuit for the second switch and verify its operation. Leave them there for the semester.

6.7. Logic analyzer

(a). Connect clock of 74163 to TTL socket of function generator. Set the frequency to about 10K Hz.

(b). Connect channel A1 to clock.

(c). Connect channel D0 of logic analyzer to clock. Also connect the ground pin of logic analyzer pod.

(d). Press Auto-scale on oscilloscope. Adjust the oscilloscope so that you can observe the two channels in detail. Record both waveforms.

(e). Remove the connection from 74163 and put on a 3M clip.

(f). Connect clock, Qa, Qb, Qc, Qd and Reset of 74163 to channels D0, D1, D2, D3, D4 and D5 of logic analyzer.

(g). Press Auto-scale on oscilloscope and observe the waveform. Adjust time base to see the effect.

(h). Sometime the input sequence can be very long and the logic analyzer is not able to capture all of them. We can set trigger to capture of the part of particular interest. The procedure to set a simple trigger pattern is:

- Press Pattern button and the corresponding soft menu shows up
- Use Select knob to choose a channel.
- Use soft menu to assign the desired value (can be H (high), L (low), X (don’t-care), low-to-high transition or high-to-low transition).
- Repeat two previous steps to set values for all the desired channels.
(i). Set the trigger pattern to the initial point of the counting sequence (i.e., $Q_a Q_b Q_c Q_d = 0000$) and press Auto-scale. Record the waveform. $\text{(i)}$

(j). Set different patterns and experiment with them.

(k). Logic analyzer is the key equipment for our course. It is a good idea to spend some time to get familiar with it. If you have time, read chapter 3 of HP user guide and try other features of the logic analyzer.