LAB 2: INTRODUCTION TO LAB INSTRUMENTS

The purpose of this lab is to introduce the basic lab instruments - digital oscilloscope and power supply. You will build a few very simple circuits and verify their operation.

You should also read the Lab Instrument Reference Guide, best viewed on the web site since it contains color annotation, for an overview and basic operating procedures of the lab instruments you will be using. At the end of this lab, your TA will give you a **timed**, practical examination on the use of these instruments.

**Hardware Required:**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LM556 Dual Timer</td>
</tr>
<tr>
<td>1</td>
<td>74LS00 Quad 2-input NAND Gates</td>
</tr>
<tr>
<td>1</td>
<td>74LS02 Quad 2-input NOR Gates</td>
</tr>
<tr>
<td>1</td>
<td>74LS04 Hex Inverters</td>
</tr>
<tr>
<td>1</td>
<td>74LS163A Synchronous 4-bit Binary Counter</td>
</tr>
<tr>
<td>1</td>
<td>4-switch DIP</td>
</tr>
<tr>
<td>1</td>
<td>LED</td>
</tr>
<tr>
<td>3</td>
<td>resistors</td>
</tr>
<tr>
<td>1</td>
<td>100 Kohm potentiometer</td>
</tr>
<tr>
<td>1</td>
<td>10 uF electrolytic capacitor</td>
</tr>
<tr>
<td>1</td>
<td>0.15 uF capacitor</td>
</tr>
</tbody>
</table>

**Preparation**

- Bring a protoboard, wire cutters, few sheets of graph for making sketches of signals.

- Check the 74LS04 and 74LS163A datasheets on the course web site and record the device pin-outs. Read the general description of each part to get an idea of how it works if you don't already know. Determine all pin numbers for connecting circuits, particularly for the inverter chain.

- Read this entire lab write-up. Note that each student will be doing the lab *individually* (i.e. - not with a partner or group) so it is important that you take responsibility for understanding what the lab requires.

- Also review the “**Tips for supporting circuits and good design practices**” section of the class website.
  a) *Lab circuit schematics* - 3 types that you should always draw for circuits you build
  b) *Active high vs. active low*
  c) *How to use switches to generate digital inputs*
  d) *Using LEDs in lab*
e) **Tips for building and debugging your circuits**

I. **HP 54600B Oscilloscope**

1. Turn on the oscilloscope and allow it to warm up for a minute or two

2. Attach a cable or 10:1 scope probe to Ch. 1 of the scope. Connect the cable or scope probe to the front-panel probe adjust signal on the oscilloscope. Adjust the voltage and time scales as necessary to display the signal. You should see a 0-to-5 V square wave displayed on the screen. Measure the period of the signal based on the time scale and calculate the frequency of the signal.

3. Press the 1 button to display the configuration settings for Ch. 1 of the scope. Make sure the Probe attenuation factor matches the probe or cable that you are using. For a 10:1 probe, the attenuation factor setting should be 10; otherwise, it should be 1. An incorrect attenuation factor setting will cause your voltage measurements to be off by a factor of 10!

   Verify that the front-panel probe adjust signal has a peak-to-peak amplitude of 5V as measured on the scope display.

   Also, make sure the Coupling option is set to DC. To toggle through any of the various configuration options, just press the corresponding softkey underneath the option displayed on the screen. (The Coupling option is displayed by pressing the 1 or 2 buttons to display the scope channel configurations.)

4. Measure the period and calculate the frequency of the square wave. You can also use the **Time** button on the front panel to automatically make the measurements.

5. Make a sketch of the waveform shown on the scope display. Label the voltage levels and the time scale. A 10:1 probe can be compensated to eliminate overshoot or undershoot. You will not actually adjust the probe compensation, but you can check to see how well it is compensated.

II. **Clock Generator Circuit**

For this and subsequent labs, you will require a clock to test your designs. You will build a clock circuit based on the LM556 timer.

a) Wire up the circuit shown in Figure 1. Your TA will provide you with all the parts needed to build this circuit. Looking down at the IC (Integrated Circuit) on the side with text facing up and with the pins facing away from you, there is often a notch indentation or a black circle indentation (depending on the manufacturer) on the IC indicating the top of the IC and the location of Pin 1. If there is a circle, Pin 1 is located directly to the left of the circle. If there is a notch, Pin 1 is located on the left most lower corner, assuming the IC is oriented notch facing upwards.

**Hint:** It is helpful to have the datasheets of the LM556 to show you the pin assignments. Remember to connect all powers and grounds. You can obtain the datasheets online or on the class webpage.
**Hint**: You will use the 556 clock generator circuit in later labs during the quarter so it will probably be a good idea to build it compactly on the side of your protoboard and leave it there after this lab.

**NOTE**: The 10μF capacitor used with the LM556 IC is polarized. Make sure the negative (-) terminal of the capacitor is connected to GND. Markings on the capacitor will indicate which leg is negative. You should use a “decoupling capacitor” between +5V and ground to filter out noise spikes. The value of the capacitor is not critical. Typical values that work well are 0.1uF and 0.15 uF.

![Clock Generator Circuit](image)

**Figure 1. Clock Generator Circuit**

**Clock Generator and Power Supply**

1. Connect the clock output of the clock generator circuit of Fig.1 to Ch. 1 of the scope. The clock should be a 0-5 V square wave. You will need to adjust the offset, amplitude and frequency knobs of the oscilloscope to see the signal clearly. What is the period and frequency measured on the scope? Draw the signal in your graphing paper and note clearly the period/frequency and the amplitude read from the scope.

2. Connect a power supply output to Ch. 1 of the scope (instead of the clock generator output). Set the power supply output to 5V DC. Verify the voltage on the scope. Is the voltage meter of the power supply accurate based on the scope measurement? (Many people read the power supply's voltage meter incorrectly - make sure that you are using the voltage scale that corresponds to the output you are using.)
III. Logic Delay Circuit

1. Using a 74LS04 IC package, connect six inverter gates in a chain as shown in Figure 2.

2. Connect the 0-to-5V square wave of your clock generator to the input of the inverter chain as shown in Figure 2.

3. Connect the input to the inverter chain on Ch. 1 of the scope and the output of the chain (i.e. the output from the sixth inverter) on Ch. 2.

4. Explain the output waveform in terms of the number of gates in the inverter chain. Make a neat sketch of the signals.

5. Measure the delay from an edge of the input signal to the nearest edge of the output signal. Please note that because the clock is much slower relative to the gates delay, it is not possible to use Auto trigger mode to get a clear reading of the delay. Instead, follow the steps below to obtain a cumulative display of the input and output signals.

   a) Set the oscilloscope’s Trigger Source to Ch. 1.
   b) Set the Time/Div to about 20ns/Div to 50ns/Div.
   b) Set the Trigger Mode to Normal.
   c) Adjust the Trigger Level knob to 50% of the input signal amplitude (2V to 2.5V)
   d) Clear the screen of the oscilloscope by pushing the Erase button on the Storage section of the oscilloscope.
   e) Observe how the oscilloscope starts reconstructing the signals connected to Ch. 1 and Ch. 2 by adding samples each clock cycle. The signal reconstruction can take a couple of minutes before they are clear enough. Be careful not to touch any knob while the scope is displaying the signals. To manually clear the screen, push the Erase button.
   f) Measure the delay and make a neat sketch of the signals.
   g) Based on your measurements, what is the average propagation delay of a single inverter gate?

6. Display the output from the fifth inverter on Ch. 2 and continue to display the input signal on Ch. 1. How has the Ch. 2 signal changed? Why? Measure the delay through the 5 gate chain and see how it compares with your result from the previous step.
IV. Frequency-divider Circuit

1. Using a 74LS163 IC package, set up the circuit shown in Figure 3. (The power and ground connections are not shown. You should check the data sheet to determine which pins correspond to power and ground pins if you don't know.)

![Circuit Diagram](image)

Figure 3. Frequency Divider Circuit

2. Connect the CLK pin to a 0-to-5V square wave signal produced by your clock generator circuit. Display the QA signal on the oscilloscope. How does its frequency compare to the CLK frequency? Display the QB, QC, QD and RCO signals on the scope, one by one, and measure the frequency of each one. Record the frequencies and their relationship to the CLK frequency.

3. Display the CLK and QA signals simultaneously on two scope channels. Set the Trigger Source to whichever input signal gives the most stable display. Sketch the waveforms of the two signals on a piece of graph paper.

4. Measure the CLK to QA delay using the cursor buttons on the scope. This delay time is measured from the 50% point of the rising CLK edge to the 50% of the QA transition (falling or rising). Adjust the t1 and t2 cursors to mark the appropriate 50% voltage points and record Δt.

5. Measure the CLK to QB, CLK to QC, and CLK to QD delays and compare them to the CLK to QA measurement. Create a table that shows the 4 delay values. Comment on what the measurements show.
V. Basic Logic Gates

1. Wire up a NAND gate with switches and an LED as shown in Figure 4. Construct a 4-row truth table showing the output for each of the four possible inputs. Calculate the value of the output current-limiting resistor so that the current through the LED is about 7.5 mA. Each pull-up resistor at the input should limit the current to about 5 mA when the corresponding switch is closed. Why is it better to turn on the LED with a low output than with a high output? Justify your answer using the 74LS00 datasheet. (Hint: Look at IOH and IOL.)

![Figure 4. Test circuit for NAND gate](image)

2. Wire up a NOR gate with switches and an LED similar to the test circuit for the NAND gate. Construct a truth table for the NOR gate.

VII. Practical examination on instrument usage

The TA will give each student a timed, practical lab examination. This examination will cover basic instrument operating procedures as described in the Lab Instrument Reference tutorial. The examination is pass/fail and may be repeated once if a student fails the first time. The TA will configure the instruments at a lab station in some arbitrary configuration and ask the student to obtain the signals specific characteristics. For example, the TA might ask the student to produce some arbitrary DC voltage on either the HP6205B or HP6237B power supplies. Another possible question would be to measure a signal’s amplitude, DC offset and frequency. Students will not be allowed to use the oscilloscope’s AUTOSCALE function key or the Voltage or Time measurement functions. Instead, students must determine the voltage and period of the signal using the vertical and horizontal grid markings and the adjustable voltage and time scale settings.
Lab Report

Each individual is required to submit a lab report. Use the format specified in the "Lab Report Information" document available on the class web page. Be sure to include the following in your lab report:

- Lab cover sheet with TA verification. (The TA will specify what he/she will verify.)
- Graded pre-lab
- Answers to all questions posed in the lab write-up
- All plots and tables required in the lab write-up

Grading

<table>
<thead>
<tr>
<th>Component</th>
<th>Points</th>
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<tbody>
<tr>
<td>Prelab</td>
<td>0</td>
</tr>
<tr>
<td>Lab checkoff</td>
<td>50</td>
</tr>
<tr>
<td>Lab report</td>
<td>50</td>
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</table>

The Lab report will be graded according to following weighting:
- Part I, Sketch and measurements: 5
- Parts II and III, Measurements: 5
- Part IV, Plot and answers to questions and values: 15
- Part V, Sketch, table, delay values, frequencies and answers to questions: 15
- Part VI, Design calculations for current-limiting resistors, experimental results: 10