Digital ICs Lab 1

Measurement Lab Manual

Preparatory Exercises

Read through the Laboratory Manual carefully and do not show up unprepared. Fill in the Preparatory questions before coming to the lab !!!!

- **What is the maximum supply voltage of the microcontroller and the ring oscillator?**

- **How does a ring oscillator work and what affects its oscillation frequency?**

- **What are the different sources of power consumption in a CMOS circuit?**

- **Which parameters affect the dynamic power consumption in a circuit?**

Purpose of this exercise

During this laboratory exercise, some measurements on CMOS circuits will be carried out to observe the typical behavior of CMOS. You will see how the performance varies with supply voltage and frequency etc. In order to be well prepared for this exercise we suggest that you read through the corresponding chapters in the main textbook, i.e. Chapters 1.3,3.2-3.3,5.4,5,5.

The equipment

In this lab you will use a circuit board with a ring oscillator, a microcontroller, and some peripheral circuitry. A sketch of the board can be found in figure 1. The ring oscillator is made up of five inverters that are connected together with a sixth inverter as an output driver. The microcontroller is programmed with three different programs. The program to be run is selected with the program select (*ProgSel*) switch. You will also experience that the microcontroller sometimes freezes up when you change the voltage or clock frequency. This can be fixed by switching off the power supply and turning it back on.

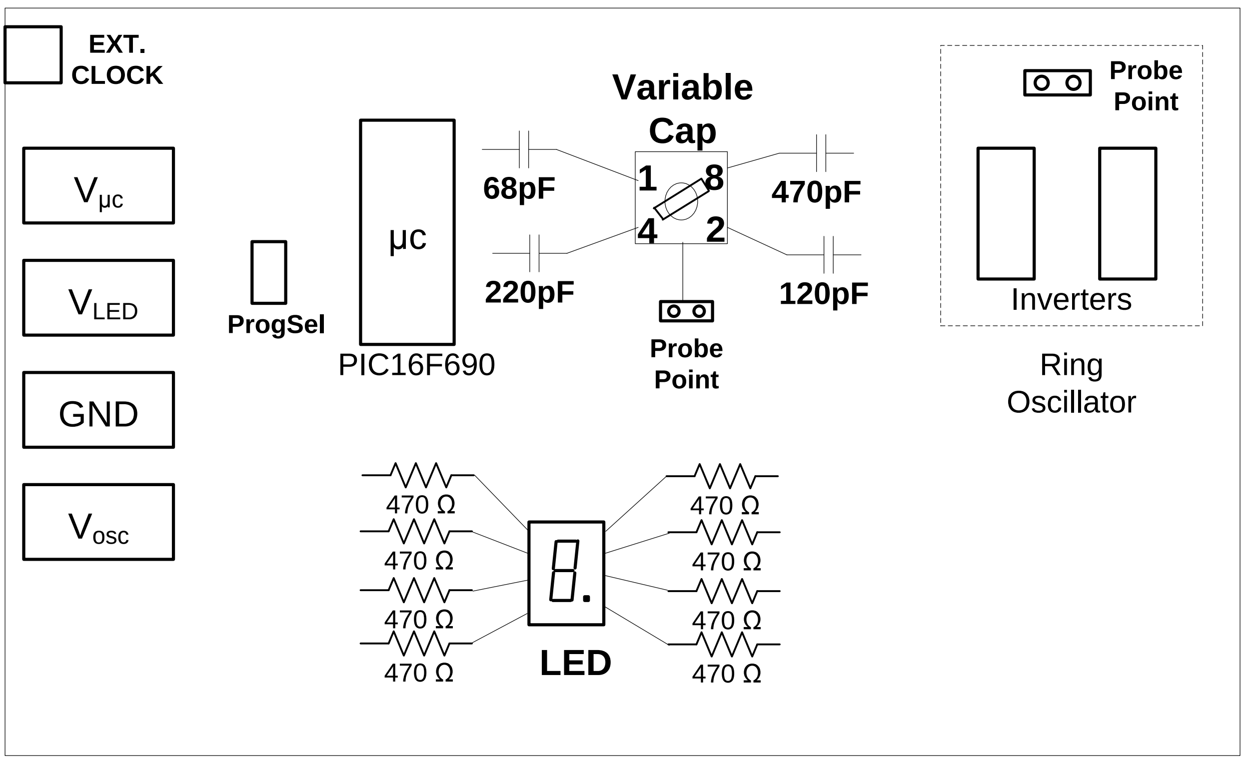

Figure 1 Layout of the Measurement Board

The board has in total seven connections, three supply voltages, one ground, two measurement probe points, and one programming connector. The programming connector is not used in the lab and hence not shown in the figure above. The purpose of the three different voltage supply connectors is to enable us to measure the power consumption of the different parts of the board easily. The Vosc connector supplies power to the two chips that make up the ring oscillator and the Vμc connector supplies power to the microcontroller. The last supply, V_{LED} supplies power to the display and some external resistors on the board. By isolating the power supplies in this way, we can measure the power consumption of the controller and the ring oscillators easily.

The maximum supply voltage for the inverters that make up the ring oscillator is 15 V and the maximum supply voltage for the microcontroller is 4.5 V. Please make sure you do not increase the voltage too much on any of these supplies as this will fry the chips.

Starting the lab

Note	**Make sure the power supply is off and that the variable supply voltage is turned down to a minimum before proceeding**. Otherwise the microcontroller may break.

Connect the variable power supply to the V_{LED} connector on the board. Also connect the Vμc connector to the same variable output via an amperemeter/multimeter. Now you can turn the power on. Connect the output of the signal (pulse) generator to the clock input on the board. Make sure that the clock signal swing is slightly smaller than the supply voltage of the microcontroller! For ex. Use 2.9 V clock swing when the supply voltage is 3 V. Do not forget to change the clock signal swing also when you vary the supply voltage in the later tasks.

Power consumption as a function of switching activity

In the microcontroller there are three different programs. You can switch between programs by using the program select switch of the microcontroller. Run the microcontroller at 10 MHz with the supply set to 3 V. Set the variable capacitor to the 0 position. Now, measure the power consumption for the three programs.

Also note down the power when the *ProgSe*l switch is pressed down i.e. when changing from Program 1 to Program 2.

Compare the power consumption of Programs 1 and 2 and comment. What is the switching activity ratio between Program 3 and 1?

Comment on why the power is different when the program switching happens i.e. *ProgSel* is in a pressed position.

Power consumption as a function of supply voltage

For this part of the exercise you should only use the first program in the microcontroller i.e. the 0-9 number pattern. Change to this program and set the clock to 10 MHz .Now, vary the supply voltage from 2 V to 4.5 V. Plot the power as a function of supply voltage in the graph provided below. Use between 6 to 8 data points in order to get a good plot.

Is this behavior of the plot as expected? Why?

Power consumption as a function of clock frequency

Set the power source voltage to 3 V and sweep the clock frequency in steps from 1 MHz to 10 MHz. Plot the power consumption versus the clock frequency. Extrapolate the power consumption at 0 MHz. Again use program 1 for this part as before.

Is the behavior linear?

As you can see there is an offset from zero in the power plot. Why?

Power consumption as a function of load capacitance

For this part of the exercise, switch to the third program i.e. the program that displays only the decimal point on the LED. Take a look at the variable capacitor switch on the board. It has 4 capacitors (also shown in Figure 1) and 16 settings from 0-F in hexadecimal. This means that you can change the load capacitance in a binary way. Bit 0 is connected to 68 pF, Bit 1 to 120 pF, Bit 2 to 220 pF, Bit 3 to 470 pF. Neglecting the pad and probe capacitance, setting 0 will result in 0 pF load capacitance, setting 3 will result in 470x0 + 220x0 + 120x1 + 68x1 i.e.188 pF.

Similarly, setting A will result in 470x1 + 220x0 + 120x1 + 68x0 = 590 pF.

In this way, you can vary the total load capacitance at the pad from 0 to 878 pF. Set the supply voltage to 3 V and clock frequency to 10 MHz. Vary the capacitance as explained above and plot the variation of the power with load capacitance.

What kind of variation do you see? Is this expected?

Based on the three previous plots, does the relation for the dynamic power consumption, $P = \alpha C_{load} V_{DD}^2 f$ seem correct?

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Rise- and fall-time with different loads

Keep the setup same as the previous exercise i.e. Program 3, 3 V supply, 10 MHz clock. Observe the output of this program on the oscilloscope using the Probe Point located just below the variable capacitor (refer Figure. 1). You should be able to observe a toggling waveform on the scope.

Observe how the rise and fall times of the output signal change as you switch the load capacitance. Measure the rise/fall times for a few capacitance settings. What is the relation between the rise time and load capacitance?

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Use the highest capacitance setting and measure the rise and fall times of the signal. Use these values to calculate the mean current drive capability of the output buffer. What is it for the rising edge? And for the falling edge?

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There is a difference in rise and fall time for the output. Why?

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Minimum Operating Voltage of the MicroController

Continue to remain in Program 3 and use a clock frequency of 20 MHz now. Change the variable capacitor setting to 0. Continue to observe the output of this program on the scope through the probe point. Now reduce the supply voltage and find the lowest voltage at which you are able to still see the output waveform on the scope.

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You can see that the controller works below a 2 V supply voltage and 20 MHz clock. Although the microcontroller has an operating range of 2-5 V between –45°C to +85°C and a frequency of 0—20 MHz, it still works outside this range. Any comment on this?

The Ring Oscillator

Now it is time to use the ring oscillator. Disconnect the previous measurement setup. Remove the power from the V_{LED} connector and move the power connected to the Vμc to the Vosc connectors. Vary the supply voltage from 15 V down to lowest possible and measure the oscillation frequency using an oscilloscope. Plot the oscillation frequency versus supply voltage.

Is it a linear behavior?

Is it possible to use the ring oscillator even in sub-threshold?

Now you are going to measure if the oscillation frequency is temperature dependent. Set the voltage to 10 V and heat (don't melt) the ring oscillator and see what happens. How is oscillation frequency affected by temperature changes and why?

Date & LiU-ID of Student

Signature of Lab Assistant