Lab Report

PX1015 - Experiment 5 - Counting and Timing

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Abstract

The following experiments explore how digital counting can be used to collect very precise Data from experiments. The Experiments especially focus on how to use the digital counters to measure time intervals very precisely. This enabled measuring human reaction time, the frequency up to which a human can discriminate between flashes of an LED and the acceleration of a falling ball. With this goal in mind, the setup, lead to an exploration of the fundamentals that go into digital counting, like wiring up a circuit, using a function generator, using an oscilloscope and learning how digital counters work.

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1 Introduction

Our modern world is heavily relying electrical circuitry. More specifically integrated ones (ICs). A common way how such circuits operate is by having a clock cycle. I. e. they do something every pulse. Today the most advanced circuits (computers) run with frequencies (clock cycles per second) of up to a few billion Hz (Ghz). A very basic circuit that can make use of a such cycles is a counter. It simply counts +1 for every pulse it receives. If the pulses are at a constant frequency this method can also be used to measure time.

2 Theory

2.1 Electrical

When wiring up any electrical circuitry some base theory is needed. First there is Ohms law, it tells us how resistance, Current and Voltage are related:

$$I = \frac{V}{R}$$

The law is helpful, whenever we need to figure out how to wire up a component that has limits on either Current or Voltage, or how a resistor (i.e. any consumer) will affect the circuit. It tells us that the current is inversely proportional to the resistance. Thus if we want to decrease the current we need to increase the resistance. Then there is also the Laws on how to combine resistors:

Series:

$$R_T = R_1 + R_2$$

Parallel:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

They tell us that if we combine resistors in parallel the overall resistance will decrease. On the other hand if there are combined in series their resistance will add up.

2.2 Binary counting

Digital circuits know two basic states off and on (0 and 1). They can't handle other values. So in order to count they can't use base 10 (0-9) and need to use base 2/binary (0-1). One place of a binary number is called a bit. Here are some examples for binary numbers with their decimal counterparts:

Binary	Decimal
0000_0100	4
0000_1000	8
0001_1000	24

Translating from binary to decimal is easy. It can be done with the following formula:

$$d = n_0 * 2^0 + n_1 * 2^1 + \ldots + n_m * 2^m$$

Where n, the corresponding binary digit.

2.3 Kinematics

Furthermore some Kinematic equations will be used to calculate the acceleration (constant) of a falling object. Using two section within the objects velocity can be measured it the acceleration can be calculated by using the difference of average velocity between sections as such:

Average velocity

$$v_{avg} = \frac{l}{t}$$

We can then take the difference between v_1 and v_2 to get Δv as well as the difference between t_1 and t_2 to get Δt.

Therefore

$$a = \frac{\Delta v}{\Delta t}$$

Plugging everything in:

$$a = \frac{2(\frac{l_2}{t_2} - \frac{l_1}{t_1})}{t_1 + t_2}$$

3 Experimental Procedure

3.1 Wiring up an LED

To test and verify the electrical setup the first step was to wire up a LED. For quick reconfiguration of the circuits a breadboard was used. To operate a LED and do so safely two things have to be taken into account

1. Direction: LEDs are Diodes so they only let electricity pass in one Direction

2. Current: LEDs can only be used up to a certain current, beyond that they get broken.

Finding out the direction was done by testing which way it lit up. This can be done as the LED is not if wired up the wrong way around. To limit the current flowing through the LED a resistor wired up in parallel was used. As can be seen from $I = \frac{V}{R}$ the current can be decreased by increasing The resistance. The documentation on the LED called for a 330Ω resistor. As such a resistor was not available, instead two 160Ω where used in series instead. After connecting a 5 volt power supply the LED lit up successfully.

3.2 Function generator and Oscilloscope

The next step was trying out the function generator. As it had a 5 volt output as well it could be used as a direct substitute for the power supply. As the circuits used later needed square waves to work properly, that setting was also chosen to test the LED. To verify that everything worked properly a low, human percievable frequency of 1Hz was chosen. After turning on the function generator the LED indeed started to blink.

Next the oscilloscope was brought out to take a closer look at the output of the function generator. It was wired up as illustrated in the manual:

First the Time/div knob was set to a very high value, this resulted in just a spot showing on the oscilloscope. By centering (Position CH1) that point (0V) the oscilloscope could be calibrated. After that the Volts/div slider was set such that it lay within the 5V range of the function generator. This resulted in two spots showing. In a third step the Time/div slider was set such that the time interval was close to what the function generator was producing as an output. The result was a square wave showing on the oscilloscope:

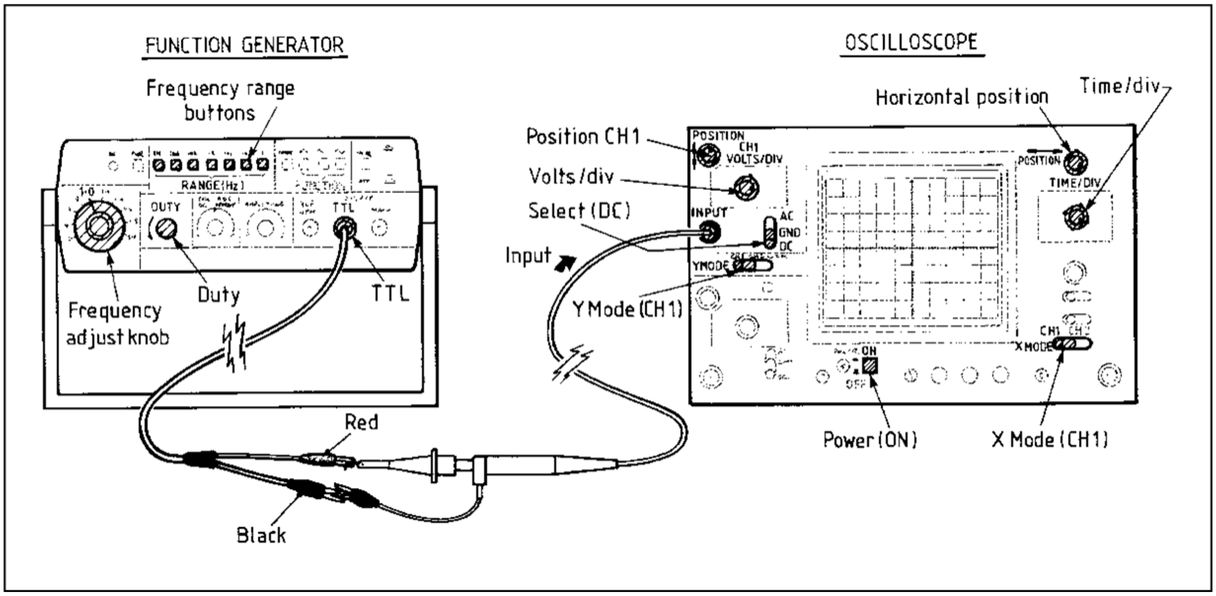

Figure 1: Function Generator wired up to Oscilloscope

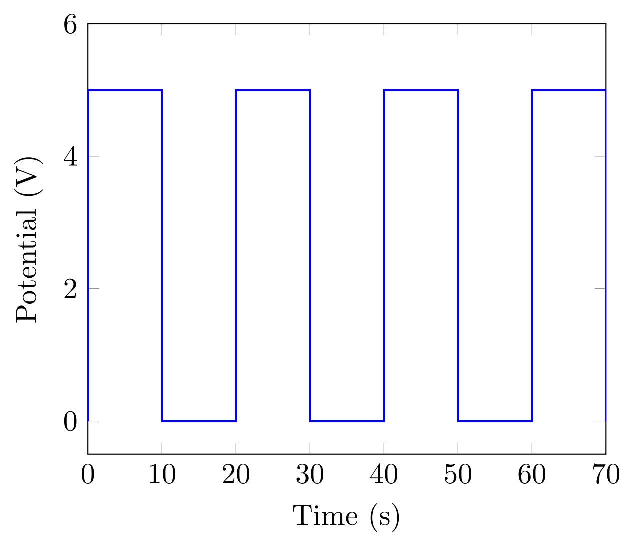

Figure 2: Idealized plotted square wave

Increasing the frequency of the function also changed how long each of the pulses on the oscilloscope. This setup now let us take a reading on what frequency the human eye can perceive. To do so the frequency was set to 100Hz (No perceivable flickering), and slowly lowered until flickering could be perceived.

3.3 Counting

To enable counting different counting where wired up instead of the LED. They needed a constant Voltage of 5V so the power supply was used again. All of the different counter circuits offered two pins to connect a clock. The function generator was connected to those pins as such a timing device. The first circuit had just two buttons start and reset without any additional pins as well as a bar of LEDs to show the current count. With it the overall setup was confirmed to be working.

Afterwards the a counting device with a 7-segment display was connected. It offered an additional switch to either use the direct output of the counting IC or put it through a binary to BCD translation IC. BCD stands for Binary-Coded-Decimal. BCD uses 4 bits per decimal digit to represent it. 4 bits are used as $2^4 = 16 > 9$.

Proceeding we wired up a circuit that counted the number of pulses within a given time period (switchable between 0.1s, 1s or 10s). By connecting the function generator again we could test how many pulses where generated by it in a given second.

Last a counting device with four 7-segment displays was connected, it could count up to 9999 (10^4). In addition it also had a start, stop and a reset button with electrical pins, that if grounded also activated the corresponding action. The stop button was then wired to a hand-held thumb-actuated button. The function generator was then set to a 1000Hz such that a value of 1 on the counter would represent 1ms. One person then covered up the start switch with their hand, reset the counter and prepared to press it. The other person held the stop button, their job was it to press it as soon as they could see the counter starting to count. This way the reaction time of the person holding the stop-button could be tested. We both recorded our reaction-times four times varying the time the person had to wait before the start button was pressed.

3.4 Measuring Gravity

With the counting circuits setup and verified we could proceed to use them to measure the gravitational acceleration on different objects. To do so a drop tower with three gates was used. Additionally two of the previously introduced four 7-segment counters where used. The gates of the tower where then wired up such that gate one was connected to the start pin of the counter one, gate 2 to the stop pin of counter one as well as the start counter of counter two and gate three to the stop pin of counter two. Thus creating a setup that could count the number of pules passing while a object traveled between the respective gates. By setting the function generator to produce an output of 1000Hz this could then be translated into time. With this setup different objects where dropped down the tower. Balls of two sizes and 4 different materials where used as well as a small pen as an object with minimal air resistance. To get additional precision the actual produced frequency displayed on the function generator was also recorded to apply it as a later correction. To improve accuracy further a run with done with the function generator set to 10,000Hz.

4 Experimental Results

4.1 Human perceivable frequencies

Person	Frequency (Hz)
Sidney	36
Bray	30

4.2 Digital Counting

BIN/BCD circuit While testing the BIN/BCD switchable counting circuit it was observed that the 7-segment display did not go through the numbers correctly all of the time. If the switch was set to BCD the counting worked correctly with the display going form 0 to 9 and then resetting. Setting the switch to BIN this did not work properly. The display was instead counting up to 6 and then did show different numbers in a random seaming way.

Function Generator output verification When connecting the function generator to the 1s resetting counter, we set different frequencies on the function generator and observed what the counter counter showed. The observation where as follows:

1. When changing the frequency on the oscilloscope it took a while for the number of counts to stabilize.
2. When pressing any of the buttons or moving the cables of the counting circuit the same happened
3. Once settled the counter showed the same value as the reading on the oscilloscope up to 1 count of difference

4.3 Reaction Time

Person	1	2	3	4	5
Sidney	242,3	225,5	156,5	163	228,7
Bray	189,5	330,5	252,9	150,2	171,1

4.4 Gravity

Material	t_0	t_1	Correction	$t0_{corrected}$	$t1_{corrected}$	g
Rubber	0,175	0,1	0,996015936	0,174302789	0,099601594	9,425604156
Wood	0,179	0,1	0,996015936	0,178286853	0,099601594	9,567281072
Plastic	0,182	0,104	0,996015936	0,1812749	0,103585657	8,714500884
Wood small	0,18	0,1	0,996015936	0,179282869	0,099601594	9,600152381
Glass small	0,181	0,099	0,996015936	0,180278884	0,098605578	9,884637057
Metal	0,181	0,099	0,996015936	0,180278884	0,098605578	9,884637057
Glass	0,18	0,099	0,996015936	0,179282869	0,098605578	9,853528837
Dart	0,1441	0,097	1,005025126	0,144824121	0,097487437	8,302050935
Metal (10kHz)	0,1765	0,0981	1,005025126	0,177386935	0,098592965	9,794882365

5 Discussion and Analysis

5.1 Digital Counting

The counting circuit s

5.2 Human perceivable frequencies

6 Conclusion