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Cost Analysis of Stopwatch Circuits Made with Arduino Development Board and Digital Integrated Circuits

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Abstract

Applications such as stopwatch, digital clock and counter are among the most frequently used applications in the digital world. In this study, we focus on the stopwatch circuit by taking it as an example. The main function of a stopwatch is to keep, control and manage time. The goal here is how to design and realize a low cost, power efficient and less latency stopwatch. In this project, the 4-digit up counter was designed and implemented using Arduino development board and classical digital circuit elements. It was also simulated using the Proteus package program. A comparison was made between the two presented methods in terms of cost, performance and power consumption. As a result of the comparison, the lowest cost, highest performance and least power consumption were obtained from the circuit made using classical digital integrated circuits. Therefore, digital systems designed with classical digital integration are much more advantageous, especially when mass production is needed.

Keyword

Cost analysis,
Stopwatch,
Arduino development board,
Digital integrated circuit

1. INTRODUCTION

In this study, a digital stopwatch circuit will be designed with both classical digital integrated circuits and the Arduino development board. Both circuits will be compared in terms of cost, speed and power consumption. The main purpose of this study is to directly apply development platforms such as Arduino without any research, even in the simplest circuits. However, circuits that perform the same function can be designed and implemented in a more economical and high-performance way using classical circuits. Here, the Stopwatch is considered only as an example circuit. This is valid for all electronic circuits. Of course, comparisons of other technologies and methods can also be made in this type of study. However, not only the cost comparison was made here, but also their performance and energy consumption were compared. It was thought that doing them all together would not only increase the cost but also lead to distraction of the reader.

A stopwatch is a timepiece designed to measure the amount of time that elapses between its activation and deactivation. A large digital version of a stopwatch designed for viewing at a distance, as in a sports stadium, is called a stop clock. In manual timing, the clock is started and stopped by a person pressing a button. In fully automatic time, both starting and stopping are triggered automatically, by sensors. The timing functions are

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traditionally controlled by two buttons on the case. Pressing the top button starts the timer running, and pressing the button a second time stops it, leaving the elapsed time displayed. A press of the second button then resets the stopwatch to zero. (Wikipedia, 2023)

Figure 1. Digital stopwatch (www.wharton.co.uk, 2023)

Digital stopwatch is an important timing device widely used in both industrial and daily life. Compare with conventional mechanical stopwatch, the main property of digital stopwatch includes low coast, high precision and high reliability (Yu Han Shen, 2018).

1.1. Counters

The most basic digital circuits of digital system applications such as stopwatch, digital clock and scoreboard are counters. Counters are used as the basic circuit in the stopwatch, which is the main element of this study. The performance of the counters also constitutes the performance of the stopwatch. Counters are used in this study, both in the stopwatch made with a classical digital integrated circuit and in the stopwatch made with Arduino. A 2-bit asynchronous counter is shown in Figure 2 (Demirel, 2021).

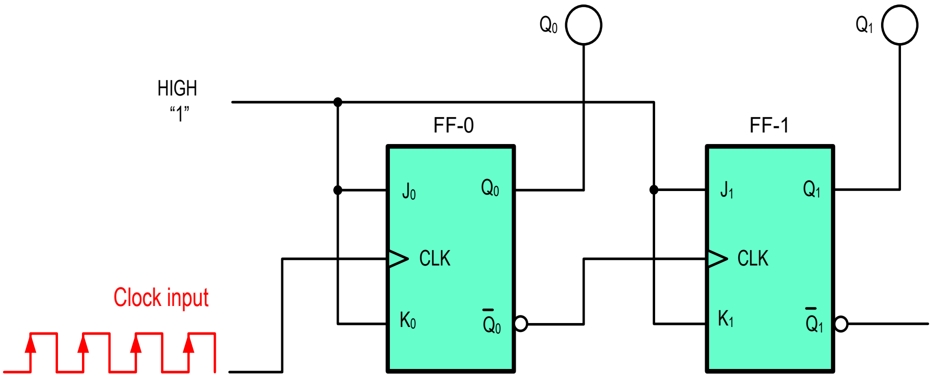

Figure 2. Two-bit asynchronous binary up counter

1.2. Propagation Delay

The time (delay time) until the input wave passes through the flip-flop (integrated) and reaches the output is called propagation delay (t_{PLH} and t_{PHL}). Propagation delay is one of the most important parameters to be considered in logic ICs. Because it is the main factor that determines the speed of integrated devices. Figure 3 shows the propagation delays (t_{PLH} and t_{PHL}) occurring in a two-bit asynchronous counter. In the figure, the time between the rising edge of the first clock pulse and the rising edge of the first flip-flop's output is indicated by t_{PLH}, which means low level to high level. The time between the rising edge of the second clock pulse and the falling edge of the first flip-flop's output is also indicated by t_{PHL}, which means high level to low level. (Floyd, 2014).

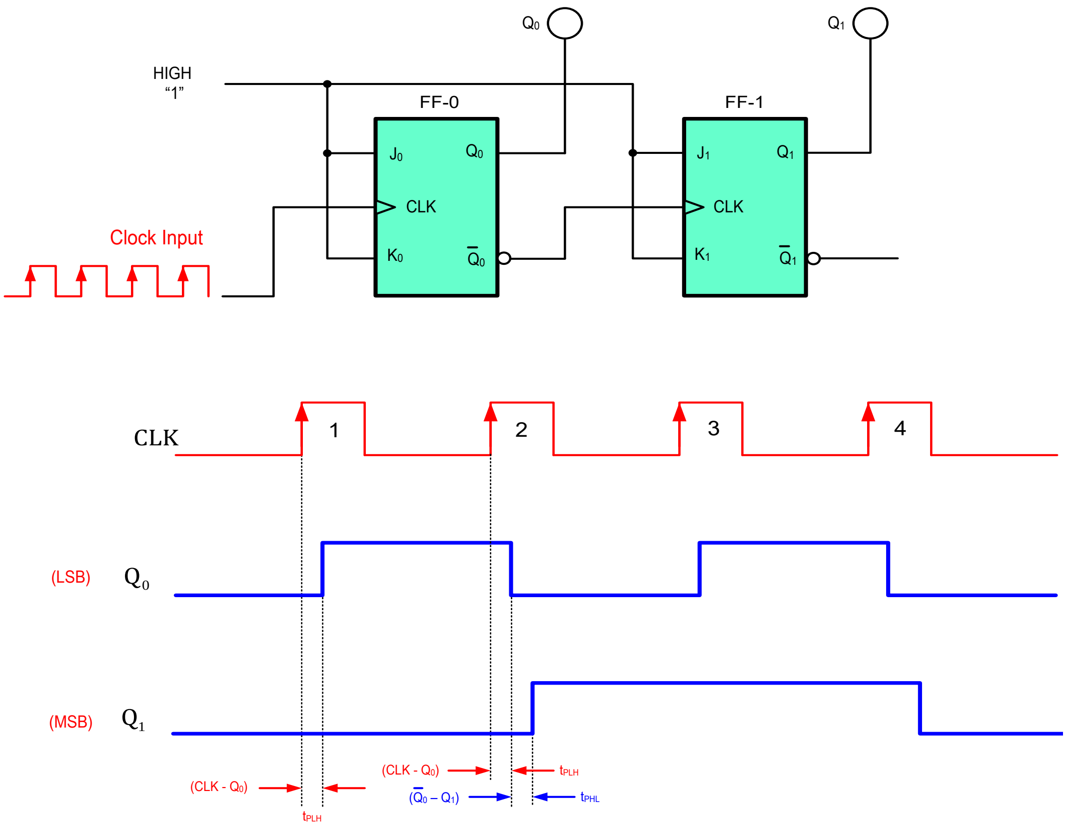

Figure 3. Propagation delays in a 2-bit asynchronous binary counter.

Propagation delay is not a valid parameter only for counters. It is also used for the delay between input and output of logic gates and even for the delay between input and output of integrated circuits and microprocessors. It is the most important parameter that determines the performance of circuits and systems.

1.3. The Arduino Platform

Is an open-source building and programming platform for electronics. Most devices can receive and send information from it, and it can even send commands to a particular electronic device over the internet. It programs the board using software and a hardware circuit board (Kondaveeti et al, 2021). Due to its user-friendly or simple interface, Arduino is frequently used in microcontroller programming today. Like any microcontroller, an Arduino is a circuit board with a chip that can be programmed to perform a wide range of tasks (Srinivasan et al, 2021). It sends information from the computer program to the Arduino microcontroller before sending it to the particular circuit or machine with multiple circuits to carry out the specific command. An Arduino board's components can be divided into two groups: software and hardware (Demirel, 2022).

Hardware Components :

The Arduino development board is made up of numerous parts that work together to make it function (Louis, 2016). As depicted in Figure 4.

- Microcontroller: At its core, the development board functions as a miniature computer that can send and receive data and commands to the peripheral devices it is connected to. Every board uses a different microcontroller, and each one has different requirements.
- External Power Supply: The Arduino development board is powered by this power supply, which has a regulated voltage range of 9 to 12 volts.
- USB plug: This port on the board is extremely important. Using a USB cable, it is used to upload (burn) a program to the microcontroller. In situations where the external power supply is not present, it also has a regulated 5V power source that powers the Arduino board.
- Internal Programmer: Without an external programmer, the developed software code can be uploaded to the microcontroller via a USB port.

- Reset button: This button can be used to restart the Arduino microcontroller and is present on the board.
- Analog Pins: Analog input pins from A0 to A7 are typically available. The analog input and output are handled by these pins.
- Digital I/O Pins: These pins range from 2 to 16 for digital input (typically). The digital input and output are done using these pins.
- Power and GND Pins: The development board has pins that can pass 3.3 and 5 volts as well as ground through them. (Badamasi, 2014)

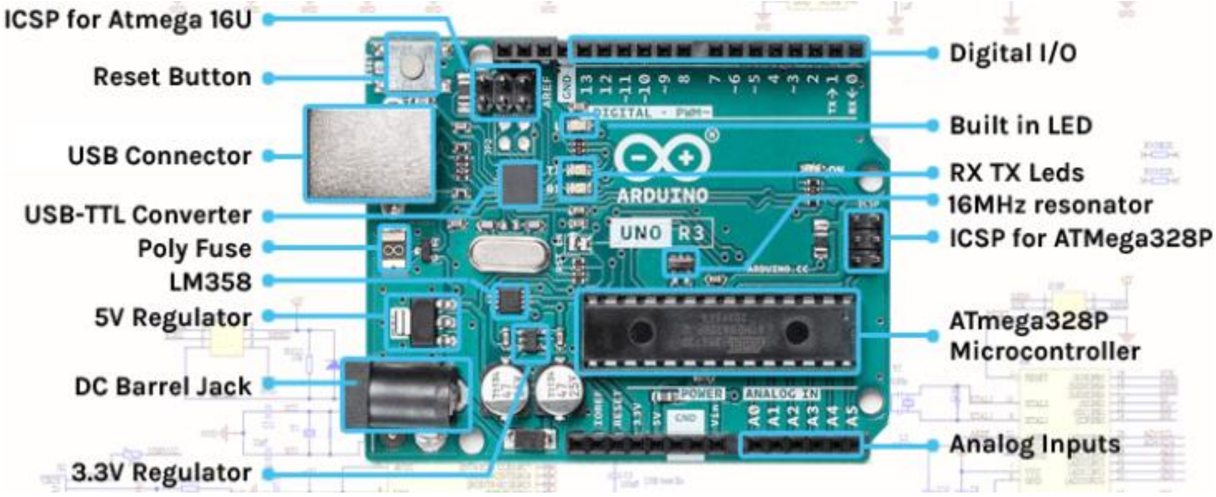

Figure 4. Labeled diagram of an Arduino Board

Software Components :

A "sketch" is the term used to describe the Arduino program code. The Arduino IDE is the name of the program used to create these sketches for an Arduino (Louis, 2016). The following components are included in this IDE:

- Text editor: Here, a simplified version of the C++ programming language can be used to write the code that has been simplified.
- Message area: It shows errors and provides feedback for exporting and saving the code.
- Text: The console presents the text output generated by the Arduino environment, which includes error messages in their entirety and other information.
- Console Toolbar: This toolbar includes a variety of buttons, including Verify, Upload, New, Save, Open, and Serial Monitor.

2. METHOD AND MATERIAL

In this project, we will use two different approaches to design a 3-digit up counter. The first approach will use a traditional digital counter (using IC74LS93 and BCD-to-seven-segment-display drive 74LS47) to implement the first circuit and the second approach will use an Arduino to design a counter. The simulation will be done using the Proteus programming language. The propagation delay time between input and output signals in both experimental lab and simulation result by (software) circuits will be used as the basis for comparison between all methods presented. Oscilloscope and other measuring devices with 100 MHz bandwidth used in the experiments are measuring devices with international certificates and accreditation.

2.1. Traditional (Classical) Digital Counter

Technically, the classical counter diagram contained four main modules as shown in Figure 5; they were: the 555 timer, decade counter 74LS93, the BCD to 7-segment-display driver 74LS47, and the 7-segment LED 4 display.

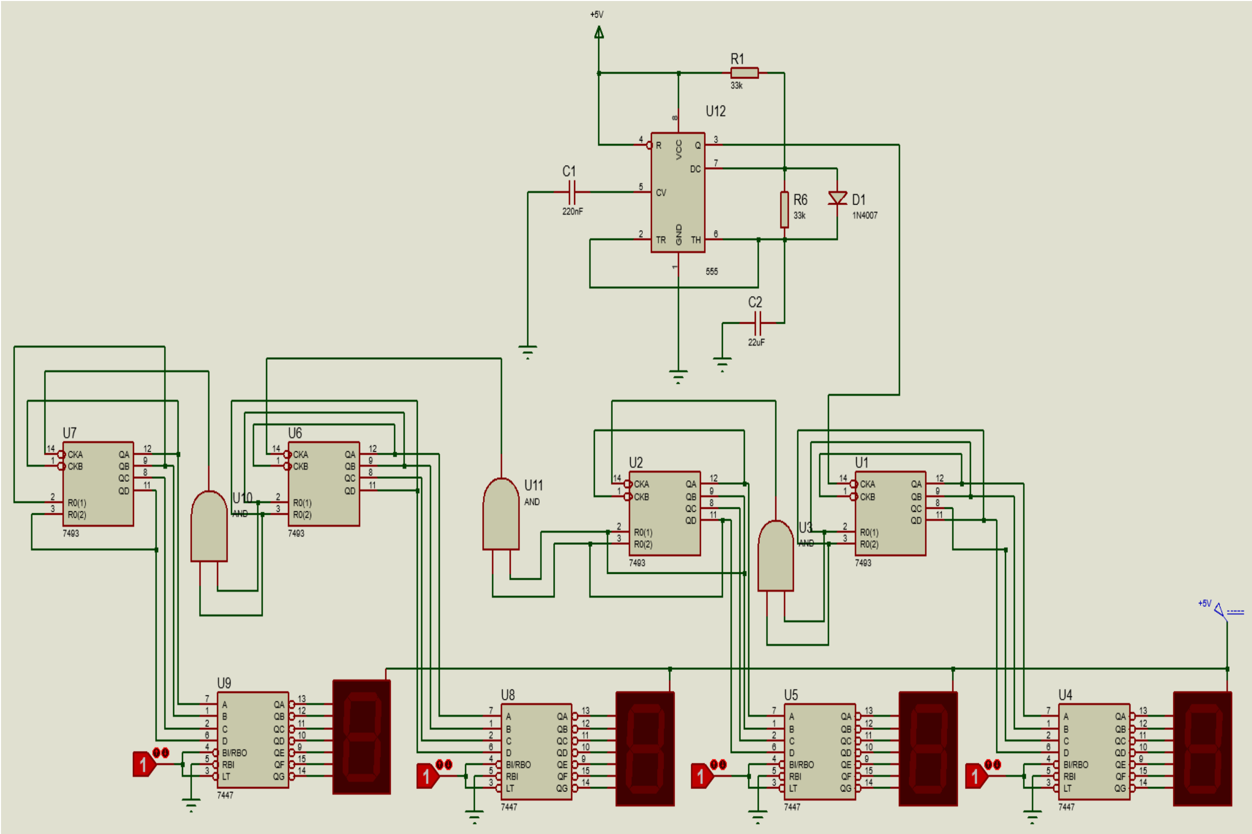

Figure 5. Schematic of the classical digital circuit

The first module. The 555 timer, was an IC[3] and produced a 1 Hz signal at the output pin 3. In other words we wanted the 555 timer circuit to keep time by sending an electrical pulse to the second module, the decade counter 74LS93, every second. There were some external electronic passive components such as resistors, capacitors and, diode associated with the 555 timer IC. Resisters values were R1=33KΩ, R2= 33KΩ, and capacitors values were C1=220nF, C2=22nF. The diode value was 1N4007. The external components determined the frequency of the output signal. The second module, the decade counter 74LS93, was an IC. This IC would count the number of electrical pulses arriving at the input pin 14. The number of pulses counted would appear in binary form on four output pins 12, 9, 8 and 11. It should be noted that the 74LS93 IC would only be able to count from zero to nine in decimal value. When the tenth pulse arrived at the input the binary output would be reset to zero, and the IC would start counting from zero.

The third module, the BCD-to-seven-segment-display drive 74LS47 for common-anode LED types, was also an IC. The second module had four output pins corresponding to four bits of a binary number. This binary numbers would have a decimal value ranging from zero to nine. This 74LS47 IC in the third module took the four outputs of the 7493 IC and converted them to seven outputs. The four input pins of the 74LS47 IC were 7, 1, 2 and 6; the seven output pins were 9, 10, 11, 12, 13, 14, and 15. The last module was the 7-segmcnt LED display, and it received signals from the 74LS47 IC's output pins. The internal Light Emitting Diodes, LEDs. Of the 7-segment LED display would be lit up depending on the signals coming from the seven outputs of the 74LS47 IC. If the coming signal was high or 5V, then the corresponding LED would be turned on. In contrast. If the signal was low or 0V, then the corresponding LED would be turned off. The third and fourth modules (BCD-to-seven-segment-display drive 74LS47 for common-anode LED type and 7-segment LED display), these components will be used in all three approaches.

2.2. Arduino UNO Circuit

Second approach for design a counter, as shown in Figure 6, the circuit consists of Arduino as a core component, the Arduino UNO is connected to the computer by USB connector installed on the Arduino device to transfer the program to ATmega328P microcontroller. The circuit also contains BCD-to-seven-segment-display drive 74LS47 for common-anode LED type and 7-segment LED display. In this circuit we chose a Timer 1 type.

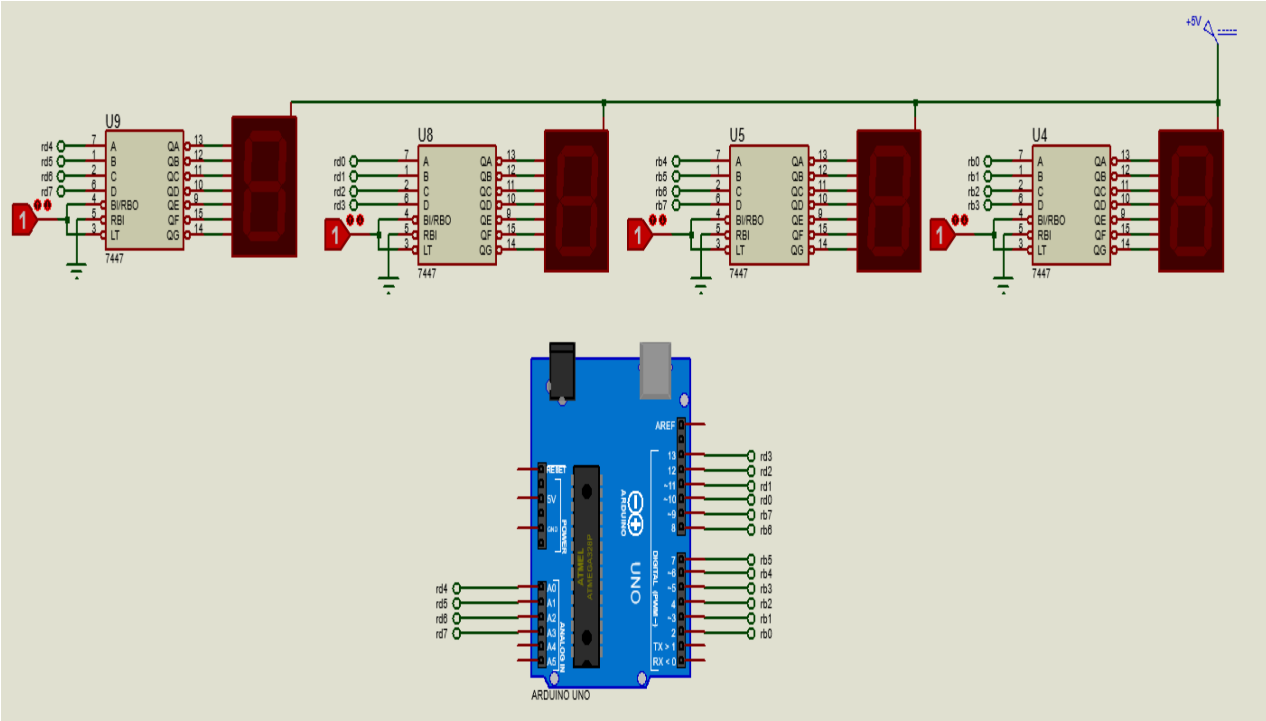

Figure 6. Schematic of the Arduino circuit

3. RESULTS

As shown in Figure 7 and Figure 8 the results we obtained by using the Proteus Simulation to measure the time delay for the three methods that were used in this study.

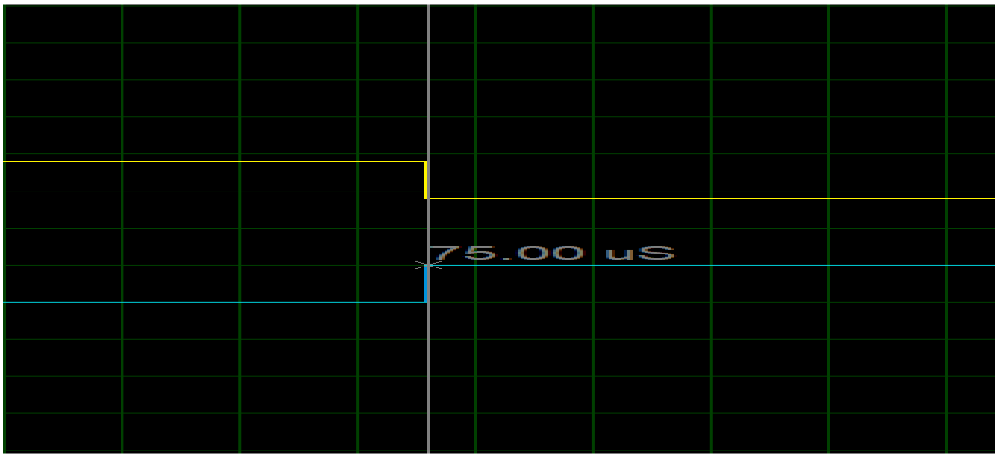

Figure 7. Proteus simulation time delay for classical digital circuit

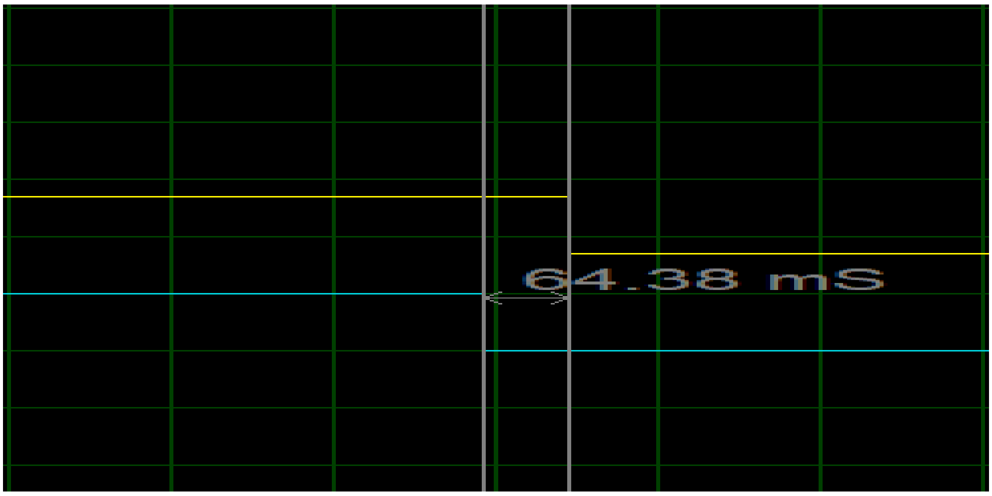

Figure 8. Proteus simulation time delay for Arduino UNO circuit

We obtained the laboratory experiments results for time delay by measured the circuits with oscilloscope as shown in Figure 9 and Figure 10.

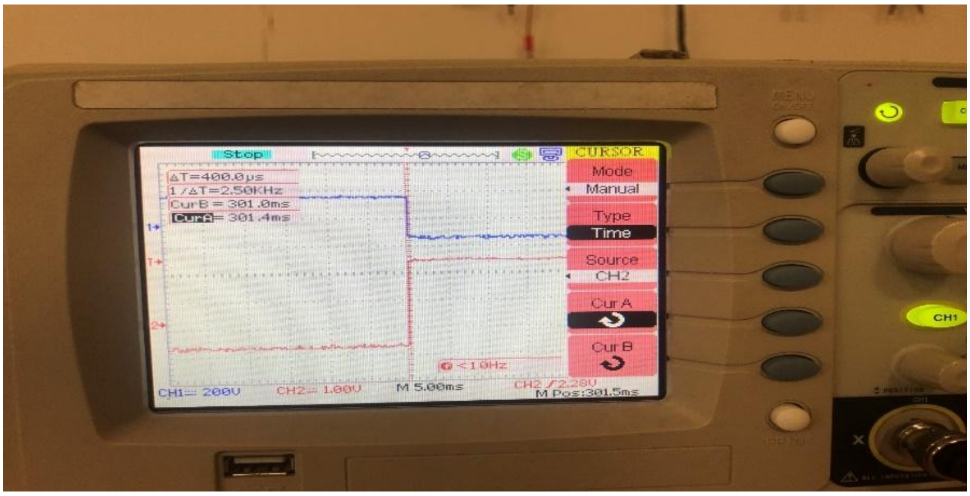

Figure 9. Experimental time delay result for classical digital circuit

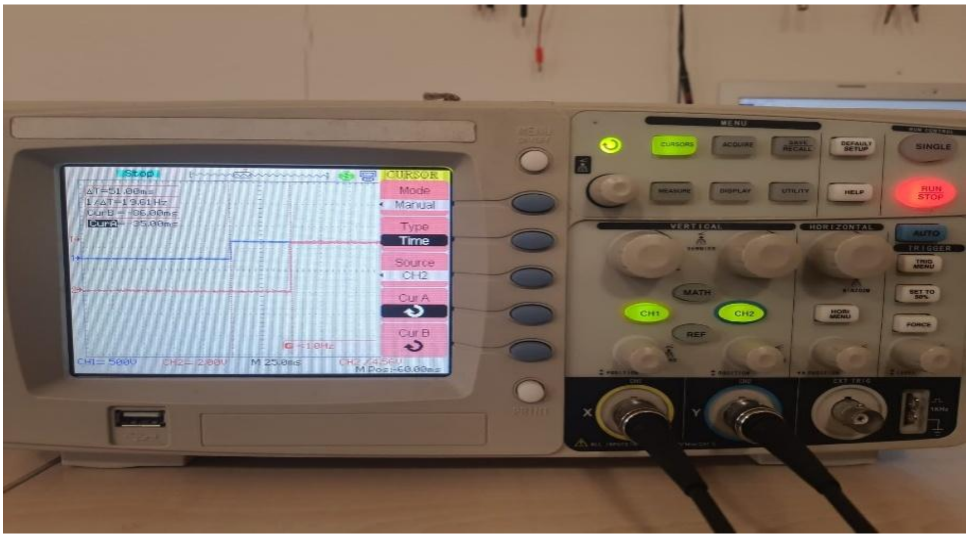

Figure 10. Experimental time delay result for Arduino circuit

Table 1 shows the measured propagation delays for both the classical digital stopwatch circuit and the stopwatch circuit built with Arduino UNO.

Table 1. Time delay results of Stopwatch Circuits

Type of Circuit	Experimental Delay	Simulation Delay
Classical	400 µs	75 µs
Arduino	51 ms	64.38 ms

Table 2 shows the measured power consumptions for both the classical digital stopwatch circuit and the stopwatch circuit built with Arduino UNO.

Table 2. Power consumption of Stopwatch Circuits

Type of Circuit	Voltage	Current	Power
Classical	5V	122.7 mA	613.5 mW
Arduino	5V	169.6 mA	848 mW

Table 3 shows the component prices and total cost for both the classical digital stopwatch circuit and the stopwatch circuit built with Arduino UNO.

Table 3. Cost of Stopwatch Circuits (According to prices from the www.direnc.net in 27.11.2023)

ARDUINO UNO PLATFORM	PRICE	CLASSICAL DIGITAL CIRCUIT	PRICE
1 x Orginal Arduino UNO Development Card	671,89 TL	4 x 74LS93 IC	31,76 TL
4 x 74LS47 7-Segment Display decoder IC	43,32 TL	1 x 555 Timer IC	3,88 TL
4 x 74LS47 7-Segment Displays	36,12 TL	4 x 7-Segment Displays	36,12 TL
1 x Bread-Board	30,69 TL	4 x 74LS47 7-Segment Display decoder IC	43,32 TL
1 x 9V DC Adapter	115,53	1 x Logic Gate IC	6,50 TL
40 x Jumper Cable	19,89 TL	2 x Resistor	1 TL
		2 x Capacitor	2 TL
		1 x Diode	1,23 TL
		1 x Bread-Board	30,69 TL
		1 x 9V Adapter	115,53 TL
TOTAL COST	**917,41 TL**	**TOTAL COST**	**248,57 TL**

4. CONCLUSION

The time delays between the inputs and outputs of the stopwatch circuit, which was first designed with two different methods, were measured in the experimental and simulation environment and are shown in Table 1. Secondly, the power consumption of the stopwatch circuit designed with two different methods was measured in the experimental environment and shown in Table 2. Finally, the costs of the stopwatch circuit implemented in both methods were determined at current market prices and are shown in Table 3.

According to Table 1. As expected in the time delay measurement, the circuit type with the least time delay was observed as the classical digital circuit (asynchronous stopwatch) in both simulation and experimental environments. As it is known, time delay is the most important parameter that determines the performance of digital systems. The less time delay, the better the performance of that system. As a result, the performance of the classic digital stopwatch is better than the digital stopwatch implemented using Arduino UNO.

Likewise, in the power consumption measurement according to Table 2, it was observed that the circuit type that consumed the least power in terms of time was the classical digital circuit (asynchronous stopwatch). Today, in addition to the performance of digital systems, one of the most important quality criteria is the energy savings of the systems. It is understood that the classical digital stopwatch circuit has a significant advantage under this heading.

Finally, both stopwatch circuits were compared in terms of cost. According to Table 3, it is seen that the cost of the Classic digital stopwatch circuit is much lower. The cost of the stopwatch circuit using Arduino UNO is more than three times (3.7 times) the cost of the classic digital stopwatch circuit. It is clear that the classical digital circuit has a great advantage, especially in mass production, and increases competitiveness significantly.

As a result, looking at all measurement results, the best results were obtained with the classical digital circuit. Performance (speed), energy saving and low cost are generally always the most important parameters in all systems. This also applies to digital systems. When these parameters were measured on a digital stopwatch circuit, it was observed that classical digital circuits had a great advantage in every aspect.

In conclusion, although circuit design and installation with the Arduino development board has become very popular in recent years, the use of Arduino for non-complex and widely used digital circuits such as stopwatches is not efficient in terms of performance, power consumption and cost. This situation has been proven in this study. If we were to make an analogy: Just as it would be illogical for a general to stand guard in a sentry box instead of a soldier in a military barracks, using Arduino even in the simplest circuits is illogical and inefficient. Even in the simplest circuits, development platforms such as Arduino are used directly without any research. As seen in this study, this situation is extremely costly. However, the same function can also be performed using classical circuits. It is both economical and much more suitable in terms of performance and power consumption. Especially in productions involving mass production, this cost will increase even more. Here the Stopwatch is just an example circuit. This is valid for all electronic circuits. Therefore, this study will shed light on the entire electronics industry.

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