12 Hour Clock
Using
Sequential Circuits

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Abstract

This project involves the design and implementation of a non-microcontroller-based digital clock using crystal oscillators, decade counters, and seven-segment display driver ICs. A crystal oscillator is used to generate a stable and accurate clock signal, which is then divided and processed through a series of decade counters to achieve precise time counting. The system is configured to display time in a 12-hour format, with appropriate logic for hour rollover. Seven-segment display ICs are used to drive the displays, ensuring clear and reliable visualization of hours and minutes. This project emphasizes the use of fundamental digital electronics components and demonstrates an in-depth understanding of timekeeping, frequency division, and display interfacing without relying on microcontrollers.

Acknowledgements

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Introduction

1.1 Background

In today's academic environment, electronic devices have become an essential part of students' daily study routines. To better understand the extent of digital device usage and its impact on focus, we conducted a campus-wide survey using Google Forms and received over 30 responses from students across the campus. The results highlighted a strong dependence on electronic devices for academic purposes, with a majority of students reporting that 76%–100% of their studies require the use of electronic devices. Notably, no respondent indicated minimal (0%–25%) reliance on digital devices, emphasizing how deeply integrated technology is in modern education.

However, the survey also revealed significant challenges associated with this dependence. When asked about the effect of smartphones on concentration, 50% of students reported that focusing on studies becomes harder when their phone is nearby, while 43.75% indicated that this happens sometimes. Only a small fraction of students felt unaffected. This clearly suggests that smartphones act as a major source of distraction, even when not actively in use.

Further investigation into the reasons behind this distraction showed that 80% of students check their phones during study sessions primarily to see the time. Despite phones being kept on silent, this seemingly harmless action often leads to unintended distractions such as notifications or endless scrolling, negatively impacting productivity and focus.

Based on these insights, we identified the need for a simple, non-distracting alternative to checking time during study hours. This directly motivated the development of a

dedicated digital clock that eliminates the need to access smartphones while studying. Additionally, survey results showed that approximately 81% of students prefer the 12-hour time format, which influenced the design choice of the clock. By addressing a common source of distraction through a focused and purpose-built solution, the project aims to help students improve concentration and create a more effective study environment.

1.2 Project Overview

This project explores the design and implementation of digital counting and timing circuits without using a microcontroller. Instead the circuits have been implemented using widely available ICs, such as the CD4026BE, CD4060, and IC 7400 (Quad 2-input NAND gate). The focus is on understanding how these ICs function individually and in combination to achieve different counting sequences, such as decimal (mod-10), mod-12, and mod-16 counts. The CD4026BE serves as a decade counter with 7-segment display output, the CD4060 functions as a multi-stage ripple counter with an integrated oscillator for frequency division, and the IC 7400 demonstrates the use of basic logic gates in controlling and shaping counting sequences. Through this project, the practical aspects of digital counters, logic gate manipulation, and sequential circuit design are demonstrated, highlighting their applications in digital clocks, frequency dividers, and timing-based control systems. The project also emphasizes the versatility of universal gates in constructing more complex digital operations from fundamental logic blocks.

1.3 Chapter List

Provide a list of all the chapters within the report.

Chapter 2 Digital Logic Circuits.

Chapter 3 Working Of Clock.

Chapter 4 Printed Circuit Board Design.

Chapter 2

Digital Logic Circuits

Digital logic circuits are fundamental components in modern electronic devices, enabling operations in systems like computers, mobile phones and calculators by processing binary data through logic gates such as AND, OR and NOT. These circuits are essential for tasks like data storage, decision-making and control functions. They are broadly categorised into two types: Combinational and Sequential Circuits

2.1 Combinational Circuits

A combinational logic circuit is a fundamental category of digital circuits in which the output at any instant depends only on the current values of the input signals**.** The circuit has no memory of previous inputs or outputs, meaning that its behavior is entirely independent of past states. As a result, whenever the same set of inputs is applied, the output will always be the same, regardless of what inputs were applied earlier.

Unlike sequential circuits, combinational circuits do not contain any memory elements such as flip-flops, latches, or registers. There are no storage components to retain data, and there is no clock signal involved in controlling the circuit's operation. Additionally, combinational circuits do not have feedback paths from output to input. This absence of feedback ensures that the circuit's output changes immediately (after a small propagation delay) in response to any change in its inputs. Due to this open structure, combinational logic circuits are often referred to as open-loop systems.

The functioning of combinational circuits is governed entirely by Boolean algebra. Each output can be expressed as a Boolean function of the input variables, and the complete behavior of the circuit can be described using a truth table, which lists all possible input

combinations and their corresponding outputs. This mathematical foundation makes combinational circuits highly predictable, reliable, and easier to analyze and design.

Common basic examples of combinational circuits include logic gates such as AND, OR, NOT, NAND, NOR, XOR, and XNOR gates. These gates perform simple Boolean operations and form the building blocks of more complex combinational systems. For instance, an AND gate produces a high output only when all its inputs are high, while an XOR gate produces a high output when the inputs differ.

More examples of combinational circuits include:

- Adders (Half Adder and Full Adder), which perform binary addition without storing any previous carry values.
- Multiplexers (MUX), which select one of many input signals and forward it to a single output based on select lines.
- Demultiplexers (DEMUX), which route a single input to one of several outputs.
- Encoders and Decoders, which convert information from one format to another, such as a binary-to-7-segment decoder used in digital displays.
- Comparators, which compare two binary numbers and indicate whether one is greater than, less than, or equal to the other.

2.1.1 BCD to 7 Segment Decoder

A Binary-Coded Decimal (BCD) to 7-Segment Decoder is a core combinational logic circuit essential for translating digital information from a computer-readable format (BCD) into a human-readable numeric display. This circuit typically forms the interface between a counting or processing unit (like a counter IC) and a visual output device (the 7-segment display).

The decoder's primary function is to convert a 4-bit BCD input (representing decimal digits 0 through 9) into a 7-bit output code that activates the correct Light-Emitting Diode (LED) segments (labeled 'a' through 'g') to display the corresponding decimal digit. Since it has no memory, its output changes immediately upon any change in the BCD input. Fig 2a shows the display device, Fig 2b shows the segments that must be illuminated for each of the numerals, and Fig 2c

Using Karnaugh map (K-map) simplification, it can be shown that the Boolean expressions for the seven-segment display outputs are given by:

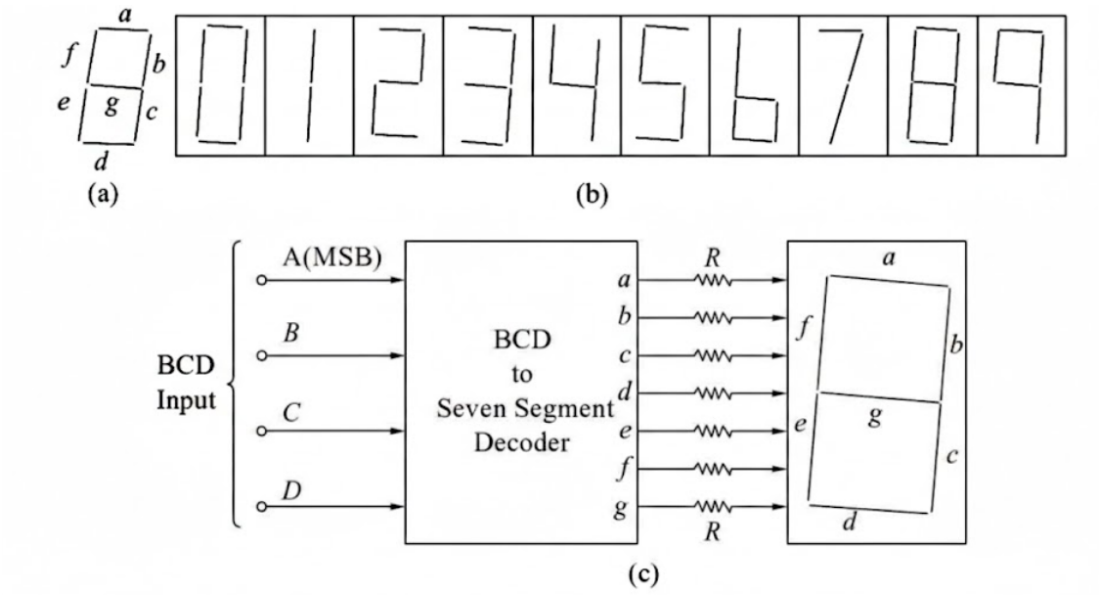

Figure 2.1: (a) 7-segment Display (b) Display of Numerals (c) Display System

$$a = \overline{B}\,\overline{D} + BD + CD + A \tag{2.1}$$

$$b = \overline{B} + \overline{C}\,\overline{D} + CD \tag{2.2}$$

$$c = B + \overline{C} + D = \overline{\overline{B}C\overline{D}} \tag{2.3}$$

$$d = \overline{B}\,\overline{D} + C\overline{D} + \overline{B}C + B\overline{C}D \tag{2.4}$$

$$e = \overline{B}\,\overline{D} + C\overline{D} \tag{2.5}$$

$$f = A + \overline{C}\,\overline{D} + B\overline{C} + B\overline{D} \tag{2.6}$$

$$g = A + B\overline{C} + \overline{B}C + C\overline{D} \tag{2.7}$$

2.2 Sequential Circuits

A sequential circuit is a fundamental category of digital logic circuits in which the output depends not only on the current input values but also on the past history of the circuit. This dependence on previous states is what gives sequential circuits their ability to remember information and distinguishes them clearly from combinational circuits, whose outputs depend solely on present inputs.

The key feature of a sequential circuit is the presence of memory elements, typically latches or flip-flops. These storage elements hold binary data representing the current state of the system. The stored state is continuously fed back into the combinational logic along with the external inputs. Based on this combination, the circuit determines

both the next output and the next state to be stored. This feedback path creates a closed-loop system, enabling the circuit to evolve through a sequence of states over time.

Most sequential circuits operate with the help of a clock signal, which synchronizes state transitions. In clocked (synchronous) sequential circuits, changes in the stored state occur only at specific moments defined by the clock, such as rising or falling edges. This controlled timing ensures predictable operation and simplifies circuit design and analysis. In contrast, asynchronous sequential circuits do not rely on a clock and change states immediately in response to input changes, although these are more complex and less commonly used due to stability concerns.

A clear distinction between combinational and sequential circuits lies in their dependence on time and memory. Combinational circuits are memoryless systems whose outputs are determined entirely by the present inputs, with no influence from previous input conditions. They do not contain feedback paths or storage elements and typically respond instantly to input changes apart from propagation delay. Sequential circuits, on the other hand, are state-dependent systems. Their outputs are influenced by both current inputs and stored past states, which are maintained using memory elements and feedback. As a result, sequential circuits can perform operations that require counting, timing, and ordered control, which are not possible using purely combinational logic.

Examples of sequential circuits include:

- Flip-Flops (SR, D, JK, T):

  These are the basic memory elements of digital systems. They store a single bit of data and change state based on input conditions and clock signals.

- Latches:

  Level-sensitive storage elements that hold data as long as an enable signal is active. They are commonly used in temporary data storage and control circuits.

- Counters:

  Sequential circuits that progress through a predefined sequence of states with each clock pulse. Examples include binary counters, decade counters, and up/down counters, widely used in timers and digital clocks.

- Shift Registers:

  Circuits that store and shift data left or right by one bit position per clock cycle. They are used for data transfer, serialization, and temporary data storage.

- Finite State Machines (FSMs):

  Systems that move through a finite number of states based on inputs and clock signals. FSMs are used in control units, traffic light controllers, and communication protocols.

- Registers:

  Collections of flip-flops used to store multi-bit data such as addresses, instructions, or intermediate results in digital systems.

- Memory Elements (RAM and ROM blocks):

  Although more complex, memory units rely on sequential logic to store and retrieve data based on control signals and clocking.

In applications such as digital clocks, sequential circuits play a central role. Counters are used to keep track of seconds, minutes, and hours by storing and updating time values with each clock pulse. The ability to retain and update state allows the system to maintain accurate time progression rather than simply reacting to instantaneous inputs.

2.3 Implementation of Digital Logic Circuits Using Integrated Circuits

Practical realization of digital logic circuits requires the use of integrated circuits (ICs). Integrated circuits package complex logic functions into compact, reliable, and standardized components, enabling efficient implementation of digital designs.

Digital systems may be constructed using simple logic ICs such as basic gate ICs or more specialized integrated circuits that combine multiple functional blocks within a single package. Basic logic ICs form the foundation of digital electronics and typically implement individual logic functions. A common example is the 7400 series IC, which contains four independent two-input NAND gates. These gates can be used to perform fundamental Boolean operations and, when combined appropriately, can realize more complex combinational logic such as AND, OR, NOT, multiplexers, and basic control logic. Due to their simplicity and versatility, NAND gate ICs like the 7400 are widely used for implementing control, reset, and decision-making logic in digital systems.

In contrast, specialized ICs are designed to perform higher-level digital functions by internally integrating multiple logic stages, storage elements, and decoding circuitry. Examples include counter ICs, oscillator ICs, and display driver ICs, which significantly

reduce circuit complexity and component count. Such ICs are especially useful in applications like digital clocks, where precise timing, sequential counting, and direct interfacing with display devices are required. By using a combination of simple logic ICs (such as the 7400 NAND gate IC) and function-specific ICs, complex digital systems can be implemented efficiently while maintaining clarity, reliability, and modular design.

In this project, a combination of such ICs was used to implement the required time-keeping, counting, display, and control logic. The following section provides a brief description of the ICs used in the project, along with their purpose and classification as combinational or sequential circuits.

2.3.1 CD4060 Timer IC

The CD4060 is a CMOS chip with a binary counter and oscillator included. It can be used to produce selectable time delays or to create signals of different frequencies. This is because it has a built-in oscillator module that only requires a few passive electronic components.

From only two resistors and one capacitor it can create 10 different frequencies . That makes it a very interesting chip, especially for those interested in audio and synthesizers.

A binary ripple counter is a circuit made up of D flip-flops in series. The output of one is connected to the CLK input of the next. The CLK input of the flip-flop on the left is the counter input.

4 D Flip-flops in series, creating a binary counter:

Instead of just four flip-flops like in the example above, the CD4060 has 14 flip-flops in series. This means it can count up to 16383 (the maximum value of 14 bits).

It also has a built-in oscillator that makes it possible to create a clock pulse to automatically increase the counter. This makes the CD4060 a timer circuit that can be used to select between different time delays (or frequencies), depending on which Q-output you use.

For example, if you choose values for the resistor and capacitor so that the oscillator creates a clock pulse of 1 Hz, it means it will increase the counter every second. So for an 8-second delay, you can use output Q4. Or for a delay of 2 hours and 16 minutes (8192 seconds), you can use output Q14.

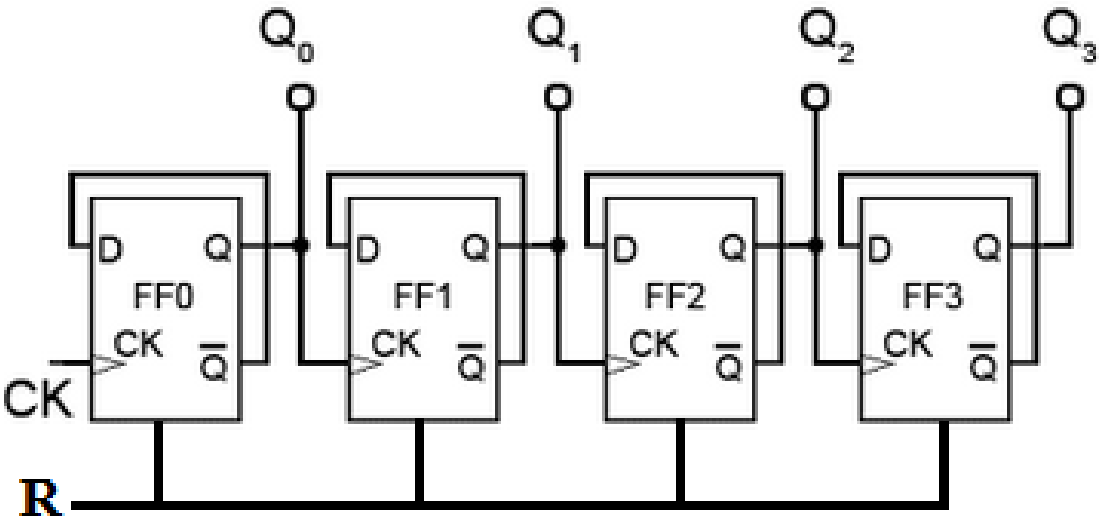

Figure 2.2: Asynchronous 4 bit Binary Counter

2.3.2 CD4026 Decade Counter / 7 Segment Display Driver

The CD4026 (or simply 4026) is a highly popular CMOS integrated circuit (IC) that serves two functions in a single package: it is a Decade Counter and a 7-Segment Display Decoder/Driver. Its unique combination of sequential (counting) and combinational (decoding) logic makes it ideal for building simple display circuits without the need for a separate decoder IC or a microcontroller. The two key features are detailed below–

1. Decade Counter The CD4026 is a 5-stage Johnson counter that counts from 0 to 9 and then automatically resets to 0. It advances the count by one on the positive-going edge (rising edge) of the signal applied to the Clock (CLK) input (Pin 1).

2. Decoder/Driver The IC has a built-in decoder that converts the internal Johnson code into a signal format suitable for directly driving a Common Cathode type 7-segment LED display. It has seven decoded outputs, labeled A through G (Pins 10, 12, 13, 9, 11, 6, 7), which correspond to the segments of the display.

2.4 Conclusions

In summary, combinational logic circuits form the backbone of digital electronics due to their simplicity, predictability, and speed. Their memoryless nature, absence of feedback, and strict dependence on present inputs make them ideal for tasks involving data processing, decision-making, and signal routing in a wide range of digital systems.

On the other hand sequential circuits enable controlled, step-by-step operation in digital systems by combining memory elements with combinational logic and feedback. Their reliance on stored state information allows them to perform ordered tasks, timing-based operations, and data storage, making them indispensable in modern digital electronics.

Chapter 3

Working Of Clock

This chapter examines the practical implementation of the digital clock project by describing the functional blocks, circuit design, and their interaction. It explains how the time-base generation, counting circuits, and display units are realized using standard integrated circuits, and how supporting components such as logic gates and decoupling capacitors ensure accurate, stable, and reliable operation of the complete system.

3.1 Overview

The clock's operation is based on the generation and division of electrical pulses that represent time intervals, and their sequential counting to display seconds, minutes, and hours. The three main functional stages are Pulse Generation, Counting Circuits (MOD-60 and MOD-12), and Digital Displays.

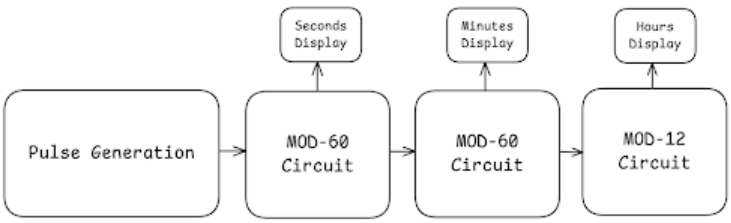

Figure 3.1: Block Diagram

At the core of the circuit lies the Pulse Generation block, which produces a continuous stream of electrical pulses at a fixed frequency. This frequency is derived from a crystal oscillator that ensures a highly stable time base. The frequency is divided down through frequency dividers or binary counters until a 1 Hz signal (one pulse per second) is

obtained. Each pulse corresponds to one second and serves as the fundamental timing signal that drives the rest of the clock circuitry.

The 1 Hz pulse is fed into the first counting stage, the MOD-60 circuit. This stage counts from 0 to 59, representing the seconds in one minute. When the count reaches 60, the circuit automatically resets to zero and generates a carry pulse that is passed to the next stage. The output of this stage is connected to the Seconds Display, which visually shows the number of seconds elapsed.

The carry pulse from the seconds counter acts as the input for the second MOD-60 circuit, which performs the same function but for minutes.The system counts the number of carry pulses received, with each representing one minute, until it reaches 60. At that point, it resets to zero and sends another carry pulse to the next stage. Its output drives the Minutes Display, showing the current minute value in digital form.

The carry pulse from the minutes section is sent to the final stage, the MOD-12 circuit, which keeps track of hours. This circuit counts from 1 to 12 before resetting to its starting point. The corresponding Hours Display shows the time in hours, completing the full digital time representation.

3.2 Pulse Generation

The pulse generation circuit serves as the fundamental time-base unit of a digital clock system, responsible for producing stable and accurate reference pulses that drive the counting stages for seconds, minutes, and hours. It utilizes two CD4060 integrated circuits, each containing a crystal-controlled oscillator and a 14-stage binary counter, to generate and divide frequency signals efficiently.

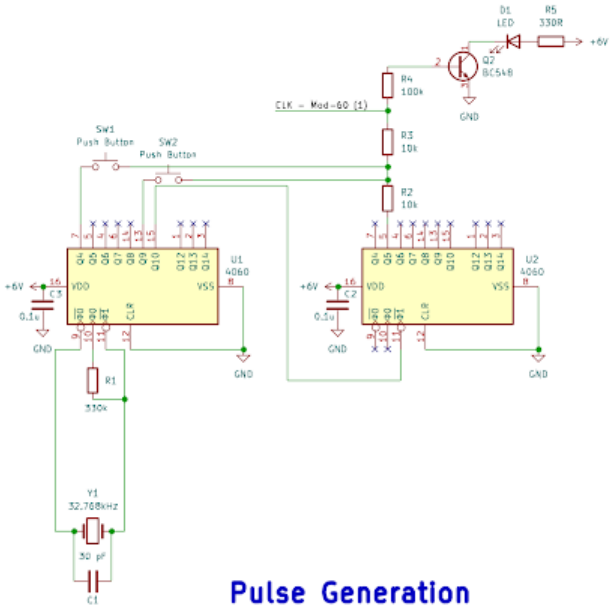

Figure 3.2: Pulse Generation Block

When a regulated +6V DC supply is applied, the first IC (U1) begins oscillation using a 32.768 kHz quartz crystal – a standard frequency in timekeeping due to its binary relationship (2^{15}), enabling easy division to 1 Hz. The crystal, along with associated components, forms a stable oscillator that generates a consistent square-wave signal. This signal is internally divided by the binary counter of U1, producing multiple lower-frequency outputs. One of these divided signals is fed to the second IC (U2), which further divides the frequency to yield a precise 1 Hz pulse, corresponding to one pulse per second.

Manual reset switches connected to each IC's reset pins allow clearing of internal stages for recalibration. Additionally, the output from U2 drives an LED through a transistor-based driver circuit, causing the LED to blink once per second, thereby providing a visual indication of proper pulse generation.

3.3 Mod-60 Counter

The MOD-60 circuit shown below forms the seconds or minutes counting section of a digital clock system. Its primary function is to count sixty incoming pulses (representing 60 seconds or 60 minutes) and display the result on two seven-segment displays. The design employs two CD4026 decade counter ICs (U3 and U4), each capable of driving a single seven-segment display directly without needing a decoder. Together, these

ICs form a two-stage counting system capable of counting from 00 to 59 in a cyclic sequence.

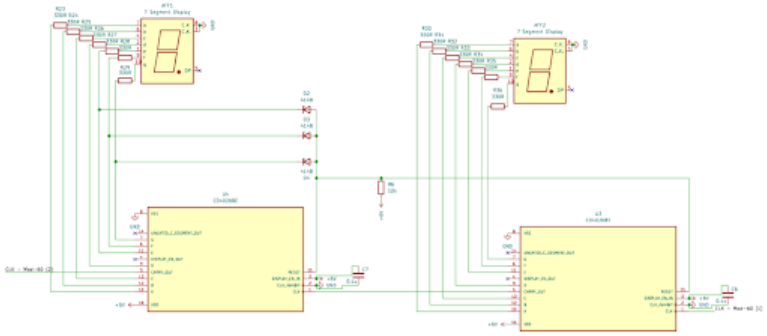

Figure 3.3: Mod-60 Circuit

The first IC (U3) receives clock pulses from the 1 Hz time-base circuit. For every ten pulses it counts, U3 advances its output and drives the first display (AFF2), showing digits 0–9. When U3 completes one full cycle (after ten pulses), its carry-out output produces a single pulse, which is fed to the clock input of the second IC (U4). This causes U4 to increment its count by one, representing the tens place (0-5) on the display (AFF1). Together, the two ICs thus count up to 59 before automatically resetting to 00, achieving a MOD-60 operation suitable for timing seconds or minutes.

Each display segment is current-limited by 330 Ω resistors to ensure proper brightness and protect the LEDs from excessive current. The circuit also includes diodes (D2-D4) and a resistor-capacitor network for noise suppression and reset stability. The manual reset and display enable features allow the counter to be synchronized or cleared when necessary.

3.4 Mod-12 Counter

MOD-12 section of the clock circuit is responsible for generating the hour count in a 12-hour format. It uses two CD4026 decade counter ICs, where the first IC counts the units digit of the hour (0-9) and the second IC counts the tens digit (0 or 1). Together, these form a restricted counter that cycles through 01 to 12 repeatedly.

The units counter (U8) receives a clock pulse from the minute section once every 60 minutes. Each pulse increments its count by one and drives the seven-segment display (AF6) through current-limiting resistors. When this counter overflows from 9 to 0, it generates a carry-out pulse. This pulse is forwarded to the tens counter (U7), making it increment once.

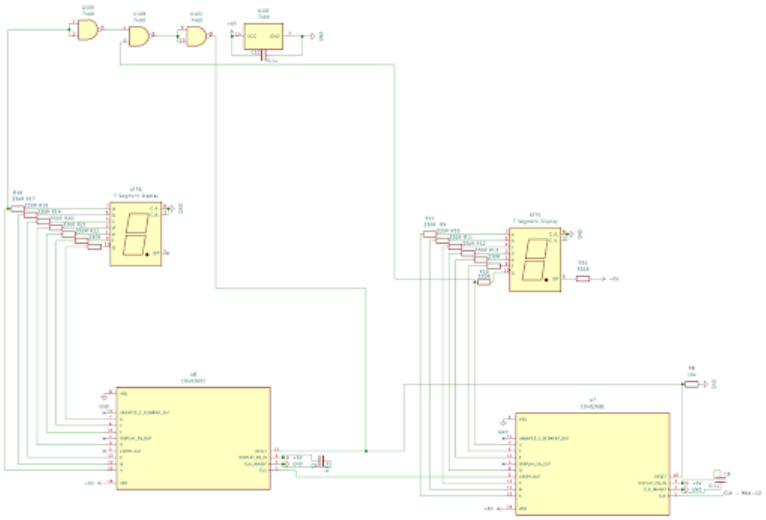

Figure 3.4: Mod-12 Circuit

The tens counter displays only “0” and “1”, representing hour ranges 01-09 and 10-12. Its outputs are connected to another seven-segment display (AF5). To maintain a proper 12-hour cycle, additional logic is required because the CD4026 naturally counts up to 9. This is handled using a set of NAND gates (from the 7400 series: U10A, U10B, U10C) which detect when the display reaches “12”.

The logic inputs are taken from specific output pins of the units and tens counters. When the units counter reaches 2 and the tens counter reads 1, the NAND gate network recognizes this combination as the terminal count “12”. The output of the final NAND gate goes high, triggering the RESET pins of both CD4026 ICs. This forces both counters to return to their initial state. Immediately on the next incoming clock pulse, the units counter advances from the reset state to display “01”, thus starting a new hour cycle.

3.5 Conclusions

This chapter presented the implementation and working of the digital clock, detailing how a crystal-controlled pulse generator produces a stable 1 Hz time base that drives the MOD-60 and MOD-12 counting stages for seconds, minutes, and hours. The use of CD4060 and CD4026 ICs enables accurate counting and direct seven-segment display driving, while additional NAND gate logic ensures correct 12-hour operation. Proper carry propagation, reset control, and the inclusion of decoupling capacitors contribute to reliable and noise-free performance, demonstrating a clear and effective application of fundamental digital electronics concepts in practical timekeeping.

Chapter 4

Printed Circuit Board Design

A Printed Circuit Board (PCB) is a rigid structure that uses conductive copper tracks laminated onto a non-conductive substrate to mechanically support and electrically connect electronic components. It is essential for ensuring signal integrity and thermal stability in complex designs by providing a robust ground plane and managed trace widths. Unlike breadboards, which are prone to loose connections and electrical noise, or perfboards/Zero PCB, which require tedious manual wiring, a PCB offers superior mechanical durability and reliability. One major advantage is the ability to use Surface Mount Devices (SMD), which can significantly save board space and account for 76% of this specific project's board. Additionally, the professional layout allows for Design Rule Checks (DRC) to ensure precise clearances and error free manufacturing.

4.1 Project Overview

This project implements a digital clock and alarm system using CMOS logic ICs and 7-segment displays. The system features:

- **32.768kHz Crystal Oscillator:** Provides accurate timekeeping frequency.
- **4060 Binary Counters:** Divide crystal frequency for second/minute/hour timing.
- **CD4026BE Decade Counters:** BCD counting with integrated 7-segment decoder/drivers.
- **Six 7-segment displays:** Display time in HH:MM:SS format (6 digits).
- **7400 NAND Logic:** Additional control logic for timing and display multiplexing.

- **User Interface:** Push buttons for time/alarm setting.

4.1.1 Decoupling Capacitors

A decoupling capacitor, often referred to as a bypass capacitor, is a fundamental component used extensively in nearly all digital and analog electronic circuits. Its primary purpose is to suppress high-frequency noise and maintain a stable local DC power supply for integrated circuits (ICs) and other active components. A decoupling capacitor in a clock display circuit is used to maintain a stable DC power supply voltage

We have implemented Decoupling Capacitors to all the Integrated Circuits (namely, CD4060, CD4026, 7400 ICs) in the schematic design of the Printed Circuit Board.

4.2 Schematic Design

Based on the actual BOM and project files, the schematic consists of these key sections:

1. **Clock Oscillator Section**
    - 32.768 kHz Crystal (Y1): Standard watch crystal for precise timekeeping.
    - 4060 Binary Counter/Oscillator (U1, U2): 14-stage binary divider.
    - Feedback Resistor ($R_1 - 330\,\text{k}\Omega$) : Provides DC bias for crystal oscillator.
    - Load Capacitor (C1 - 30pF): Sets crystal oscillation frequency.
    - Decoupling Capacitors (C2, C3): 0.1µF for oscillator ICs.
2. **Decade Counter and Display Driver Section**
    - CD4026BE Counters (U3-U8): Six decade counters, one per digit.
    - 7-Segment Displays (AFF1-AFF6): Six common-cathode displays for HH:MM:SS
    - Current Limiting Resistors (R5, R9-R52): $330\,\Omega$ resistors (45 total) for each LED segment.
    - Decoupling Capacitors (C4-C9): 0.1µF for each CD4026BE IC.

    Display Configuration:
    - Digit 1-2: Hours (01-12).
    - Digit 3-4: Minutes (00-59).

- Digit 5-6: Seconds (00-59).

Each CD4026BE provides:

- BCD decade counting (0-9).
- Automatic 7-segment decoding.
- Built-in segment drivers.
- Carry-out for cascading.

3. **Logic Control Section**
   - 7400 Quad NAND Gate (U10): Implements control logic.
   - Control Resistors (R2, R3, R6, R7, R8): (10 kΩ) pull-up/pull-down.
   - Bias Resistor (R4): (100 kΩ) for logic biasing.
   - Decoupling Capacitor (C10): 0.1µF for logic IC.
4. **Protection and Switching**
   - 1N4148 Diodes (D2-D7): Fast switching diodes for signal protection.
   - BC548 Transistor (Q2): NPN transistor for switching or signal amplification.
   - Status LED (D1): Power/status indicator with current limiting.
5. **User Interface**
   - Push Buttons (SW1, SW2): Time/alarm setting controls.
   - Pull-up Resistors: Included in R2, R3 group for button inputs.
   - Debouncing: Implemented via hardware RC network or logic gates.
6. **Power Supply**
   - Screw Terminal (J1): 2-pin terminal block for power input.
   - Power Distribution: Direct power routing to all ICs.
   - Decoupling: Each IC has dedicated 0.1µF bypass capacitor.

4.3 PCB Design

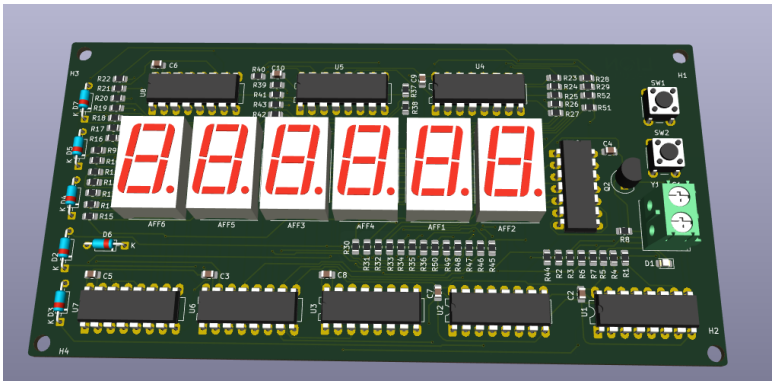

Figure 4.1: 3D View of PCB - Front View

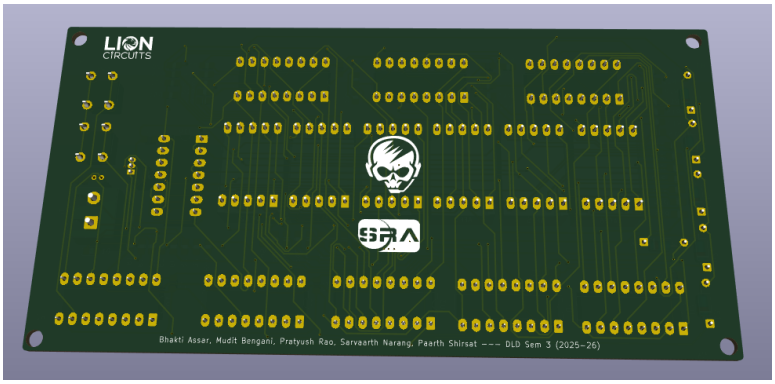

Figure 4.2: 3D View of PCB - Back View

4.3.1 Design Validation and Routing

The current design successfully passes a full Design Rule Check (DRC), ensuring all clearances and net constraints are met. Significant attention was paid to trace width management, with specific widths optimized for logic signals, LED strings, and power rails. To maintain signal integrity and thermal stability, the layout utilizes strategic via placement for complex routing and extensive ground stitching to create a robust ground plane.

4.3.2 Component Placement Strategy

Practicality and electrical performance drove the component layout. All decoupling capacitors are positioned in close proximity to their respective ICs to minimize noise and voltage ripples. The board employs a hybrid THT/SMD approach to balance educational utility with modern efficiency. While through-hole (THT) components are

used for main logic ICs to facilitate easier troubleshooting, SMD resistors and capacitors were chosen to save significant board space—a critical decision given the high count of 52 passive components.

4.3.3 Rationale and Cost Optimization

The design prioritizes both cost and mechanical durability. By selecting CD4026BE in DIP packages, the project leverages the higher availability and lower cost of THT variants compared to their SMD counterparts. Furthermore, THT was used for user interface elements like buttons and displays to take advantage of their superior mechanical strength. In contrast, the use of SOIC counters and SMD passives aligns the project with contemporary PCB design standards, bringing the total SMD count to 76% of the board.

Appendix

Glossary

Binary Counter A sequential circuit that counts in binary form in response to clock pulses. Used for frequency division and time counting.

Binary-Coded Decimal (BCD) A digital representation where each decimal digit (0–9) is encoded using a 4-bit binary number.

BCD to 7-Segment Decoder A combinational circuit that converts BCD inputs into signals required to illuminate the appropriate segments of a 7-segment display.

Carry-Out (CO) An output signal generated by a counter to indicate completion of one counting cycle, used to trigger the next higher-order counter.

CD4026 Decade Counter / Display Driver A CMOS integrated circuit that combines a decade counter and a 7-segment display decoder, capable of directly driving a common-cathode display.

CD4060 Timer IC A CMOS integrated circuit containing a crystal oscillator and a 14-stage binary ripple counter, used for generating and dividing clock frequencies.

Clock Pulse A periodic digital signal used to synchronize and control the operation of sequential circuits.

Combinational Circuit A digital logic circuit whose output depends only on the current input values and has no memory of past states.

Crystal Oscillator An electronic oscillator that uses the mechanical resonance of a quartz crystal to generate a highly stable frequency.

Decade Counter A counter that cycles through ten states (0–9) before resetting to zero.

Decoupling Capacitor A capacitor placed near integrated circuit power pins to suppress noise and stabilize the supply voltage.

Digital Clock An electronic device that displays time in numeric form using digital logic circuits.

Frequency Division The process of reducing a higher frequency signal into a lower frequency using counters or dividers.

MOD-12 Counter A counter designed to cycle through 12 states, used to represent hours in a 12-hour clock format.

MOD-60 Counter A counter that cycles from 0 to 59, used for counting seconds and minutes.

NAND Gate A universal logic gate that produces a LOW output only when all inputs are HIGH; used for control and reset logic.

Printed Circuit Board (PCB) A board that mechanically supports and electrically connects electronic components using conductive tracks.

Propagation Delay The small time delay between a change in input and the corresponding change in output of a logic circuit.

Quartz Crystal (32.768 kHz) A standard crystal frequency used in timekeeping applications due to its ease of binary division.

Reset Signal A control signal used to clear counters and force them to a known initial state.

Ripple Counter A type of asynchronous counter where the output of one flip-flop clocks the next.

Seven-Segment Display A display device composed of seven LEDs arranged to display decimal numerals.

Sequential Circuit A digital circuit whose output depends on both current inputs and previous states, incorporating memory elements.

Time Base A reference timing signal, typically 1 Hz in clocks, used to measure and control time progression.