
8086 Microprocessor Design Project

CMPE 310
Systems Design and Programming
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May 11, 2017



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1 Introduction

This document provides detailed instructions to develop an 8086 microprocessor board using Cadence® OrCAD® Capture software. Included are the schematics of individual IC components and their description. Details of the ICs include decoding, programming specifications, and descriptions of IC pinouts.

1.1 Purpose

As per the project description, this document is to serve as the only documentation of the operational and functional specifications of the Intel 8086. The documentation is to be thorough and concise to provide information to design a similar board.

1.2 Scope and Organization of Document

The document will elaborate on the individual building blocks of the 8086 board. The integrated circuit (IC) chips used in designing the board will be discussed, along with brief, high-level overviews of their pinouts, their various connections and their functionalities. The connections and dependencies between the different components such as memory and IO devices will be discussed in detail.

The document is organized into sections that cover the individual components and their IC pinouts, functionalities, connections and role in the 8086 board. Schematics of the different components and their circuitry are included. Code snippets, including the VHDL (VHSIC Hardware Description Language) implementations of the decoding hardware and the Assembly implementations of the data and memory addressing, are also incorporated in the document.

The schematics in the document are included in Appendix A and the code snippets in Appendix B. The PCB Design layouts are included in Appendix C.

2 8086 Microprocessor

The 8086 microprocessor is an enhanced version of the 8085 microprocessor developed by Intel in 1978. It is a 16-bit microprocessor, with 20 address lines and 16 data lines to provide up to 1 MB of physical memory. The 8086 microprocessor described in the project will operate in its minimum mode.

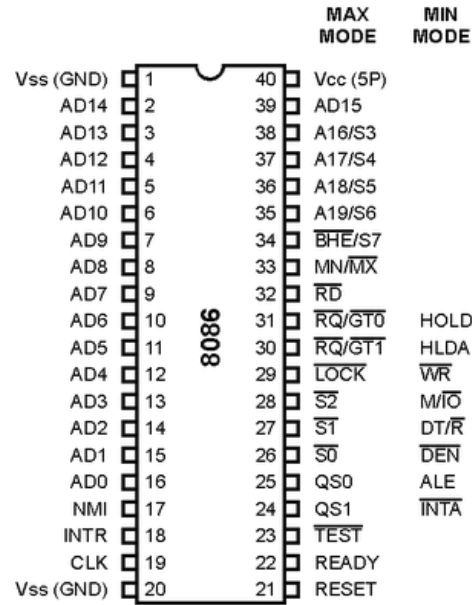


Figure 1: 8086 Microprocessor

2.1 Features

The 8086 microprocessor is known for its significant advancements since its predecessors. The most prominent features include, but are not limited to:

- 6 bytes of cache memory for faster processing
- Pipelining stages: Fetch Stage and Execute Stage
- Instruction queue
- 256 vectored interrupts
- Maximum and minimum modes of operation, suitable for multiple and single processors respectively

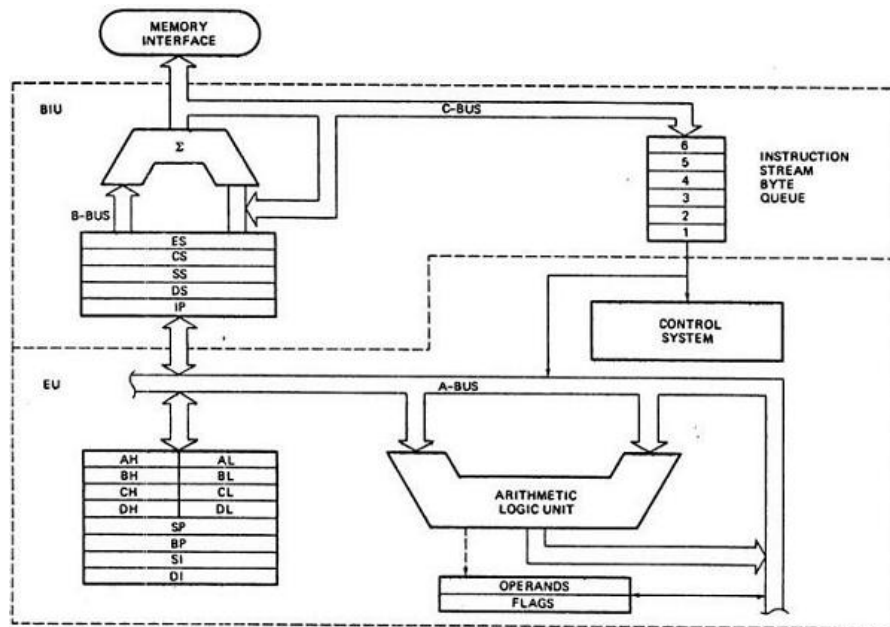


Figure 2: Architecture of 8086

2.2 Address and Data Buses

The 8086 CPU has a unidirectional address bus with 20 address lines and a bidirectional data bus with 16 data lines. [1] The address bus is used to select the desired memory or I/O device by generating a unique address which corresponds to the memory location or the location of I/O device of the system. The data bus is used to transfer data between the CPU and memory and the CPU and I/O devices.

The address bus is denoted as $A_{19} - A_0$ (20 lines) and the data bus $D_{15} - D_0$ (16 lines). The peripheral devices implemented with the 8086 in this document however consist of 8-bit data bus architectures. The data bus would therefore be multiplexed and more commonly denoted as $D_7 - D_0$ (8 lines).

2.3 Control Bus

The control bus of 8086 carries control signals which are used to specify the memory and I/O devices. [1] The bus is bidirectional and assists the CPU in synchronizing control signals to internal devices and external components. It is comprised of interrupt lines, byte enable lines, read/write signals and status lines.

3 Decoding

Discrete gate integrated chips are used throughout the board for decoding and demultiplexing address, data and control lines.

3.1 Programmable Logic Device - PAL16L8

Programmable Array Logic (PAL) is a type of Programmable Logic Device (PLD) used to implement logical functions. [2] PALs comprise of an AND gate array followed by an OR gate array, as shown in Figure 3.

16L8s were programmed to be used throughout the board to implement the various functionalities required in the system.

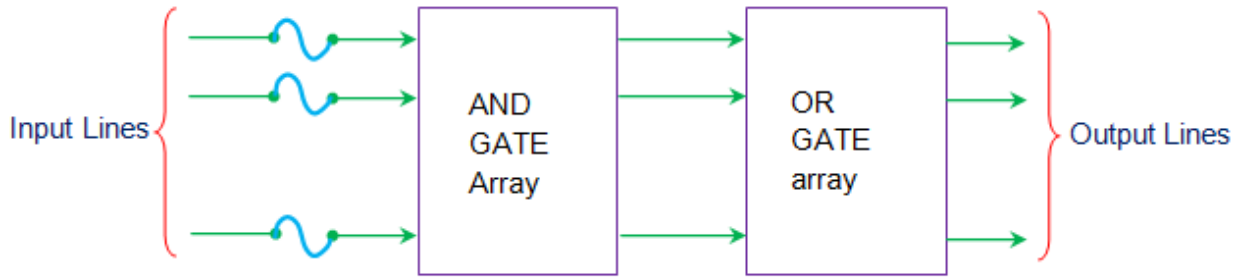


Figure 3: 8086 Microprocessor

3.2 Programming the PLD

VHSIC Hardware Description Language (VHDL) was used to program the different logical functions. The modules used for the nine (9) 16L8s used in the system are implemented in Appendix B.

4 Clock Generator - 8284A

The 8184A Clock Generator is an ancillary component to the 8086. This system clock is used to synchronize both internal and external operations using an external oscillator. The device is also used for READY and RESET synchronizations and TTL-level peripheral clock signal generation.

4.1 Clock Speed

The 8086 internal clock has a frequency of 5 MHz ($\frac{1}{3}$ of CLK). The external crystal typically oscillates at 15 MHz.

4.2 RESET Operation

Correct reset timing requires that the RESET input to the 8086 becomes a logic 1 in 4 clock cycles and remain high for at least 50 μS . The reset switch is implemented in a RC circuit with typical resistance of 100 $k\Omega$ and 10 μF .

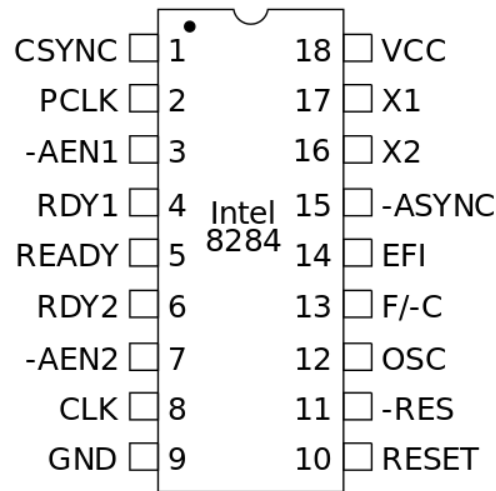


Figure 4: 8284A Clock Generator

5 Memory Architecture

The board implemented in this document consists of 128 kB of SRAM and 256 kB of CMOS flash memory.

5.1 Static Random Access Memory - CY7C199

Static RAM, or SRAM, is a type of volatile memory where bits are stored as long as power is supplied. They are ideal for cache memory because of their fast access times as low as 10 ns. CY7C199 SRAM chips are used to implement the SRAM on this system.

5.2 Addressing

The SRAM implemented in the system is composed of $32k \times 8$ CY7C199 SRAM chips decoded into two banks, with the lowest address at 0x00000.

5.3 CMOS Flash Memory - 28F010

Flash memory, or electrically erasable programmable ROM (EEPROM), is a type of non-volatile memory which maintains its state even after loss of power. Writing to this memory is much slower than a normal RAM, and it is used to store setup information. 28F010 CMOS chips are used to implement the flash memory on this system.

5.4 Addressing Flash Memory

The flash memory implemented in the system is composed of $128k \times 8$ 28F010 CMOS chips decoded into two banks, with the highest address at 0xFFFFF.

6 Programmable Peripheral Interface

The 82C55A is a popular interfacing component that can interface any TTL-compatible I/O device to the microprocessor. The chip is used to interface the keyboard and the LCD controller in the system.

6.1 Addressing

The 3 82C55 chips are decoded at the following port addresses respectively:

- 0x000F (control register), 0x000D, 0x000B, 0x0009
- 0x000E (control register), 0x000C, 0x000A, 0x0008
- 0x0007 (control register), 0x0005, 0x0003, 0x0001

6.2 Assembly Implementation and Programming of the 82C55A

A code segment of interfacing with the peripheral interface is provided in Section B.2.2 of Appendix B.

7 Programmable Keyboard/Display Interface - 8279

16 push button switches connected as four rows and four columns, 2 push button switches connected to the control and shift inputs as well as the reset switch connected to the IR0 pin of the 8259 interrupt controller and NMI keys are arranged as the 5×4 keyboard matrix into the 8279 keyboard controller for the system.

7.1 Addressing

The 8279 keyboard controller is decoded at 0x00F2 (command) and 0x00F0 (data).

7.2 Assembly Implementation

The implementation of the keyboard controller is provided in Section B.2.3 of Appendix B.

8 Programmable Interval Timer - 8254

An 8254 programmable interval timer chip is integrated into the system. The component is required to solve the common timing control problems in the microprocessor. The chip also facilitates in other aspects of the system, such as accurate time delays, real time clocks, event counters, square wave generation, etc. The 8254 has 3 independent 16-bit programmable counters, each capable of counting in binary or binary coded decimal (BCD) with a maximum frequency of 1 MHz.

All the counter gate, clock and output pins are connected to headers for external access, with the exception of Counter 2 output connected to IR1 of the 8259 interrupt controller.

8.1 Addressing

The 8254 is decoded at 0xFFEE (command register), 0xFFEC, 0xFFEA and 0xFFE8.

8.2 Programming

Each of the counters is individually programmed by writing a control word followed by the initial count. The control word is used to select the counter, mode of operation, binary or binary coded decimal counter, and the type of operation.

8.3 Assembly Implementation

A code segment of interfacing with the interval timer is provided in Section B.2.4 of Appendix B.

9 Universal Asynchronous Receiver/Transmitter - 16550

The UART is a programmable communications interface designed to connect to virtually any type of serial interface. The 16550 includes a programmable baud rate generator and separate FIFO buffers for input and output data, and is capable of transmitting and receiving data without a clock or timing signal.

9.1 Addressing the 16550

The 16550 is decoded in the high bank at odd port addresses from 0x00EF to 0x00E1.

9.2 Assembly Implementation

A code segment of interfacing with the interval timer is provided in Section B.2.5 of Appendix B.

9.3 MAX-235 and D-SUB-9

The MAX-235 is used as an intermediate step between the board and any outside connections requiring 12 V signals. The chip acts in a scaling capacity, either increasing or decreasing the signal voltage from 5 V to 12 V, or vice versa.

The D-SUB-9 is a simple connection adapter for the inputs and outputs.

10 Programmable Interrupt Controller - 8259

The 8259A programmable interrupt controller (PIC) adds eight vectored priority encoded interrupts to the microprocessor, which can be expanded up to 64 interrupt requests without additional hardware.

10.1 Addressing

The 8259A is decoded at 0xFFFF6 (command) and 0xFFFF4 (data).

10.2 Assembly Implementation and Programming

A code segment of interfacing with the interrupt controller is provided in Section ?? of Appendix B.

11 LCD Display

A 20×4 LCD display with no backlight and an integrated LCD controller are included in the board.

11.1 Addressing

The LCD controller decoded at addresses 0x00D6, 0x00D4, 0x00D2, and 0x00D0 is used to interface the LCD display.

11.2 Assembly Implementation

The implementation of the LCD controller is provided in Section B.2.1 of Appendix B.

12 LEDs and DIP Switches

2 common-anode seven-segment LEDs with a decimal point segment, 8 standalone LEDs and 8 DIP switches are also connected to and integrated into the system.

12.1 Seven-Segment LEDs

74LS374 latches decoded at 0x00CE and 0x00CF are used to interface the 7-segment LEDs.

12.2 LEDs

A 74LS374 latch decoded at 0x00CC is used to interface the 7-segment LEDs.

12.3 DIP Switches

A 74LS244 buffer decoded at 0x00CA is used to interface the 8 DIP switches.

13 External Headers

External headers are used to pull address, data and control lines and other port connections for external access.

13.1 30-Pin Headers with the 8255

30-pin headers are used to pull the port connections for external access. The connections are demonstrated on the schematic in Figure 9.

13.2 14-Pin Headers with the 8254

14-pin headers are used to pull the counters' outputs for external access. The connections are demonstrated on the schematic in Figure 11.

13.3 14-Pin Headers with the 8259

14-pin headers are used to pull the interrupt request lines for external access. The connections are demonstrated on the schematic in Figure 13.

13.4 60-Pin External Header with the Address, Data and Control Bus

30-pin headers are used to pull the address, data and control buses for external access. The connections are demonstrated on the schematic in Figure 6.

Appendix A Schematics

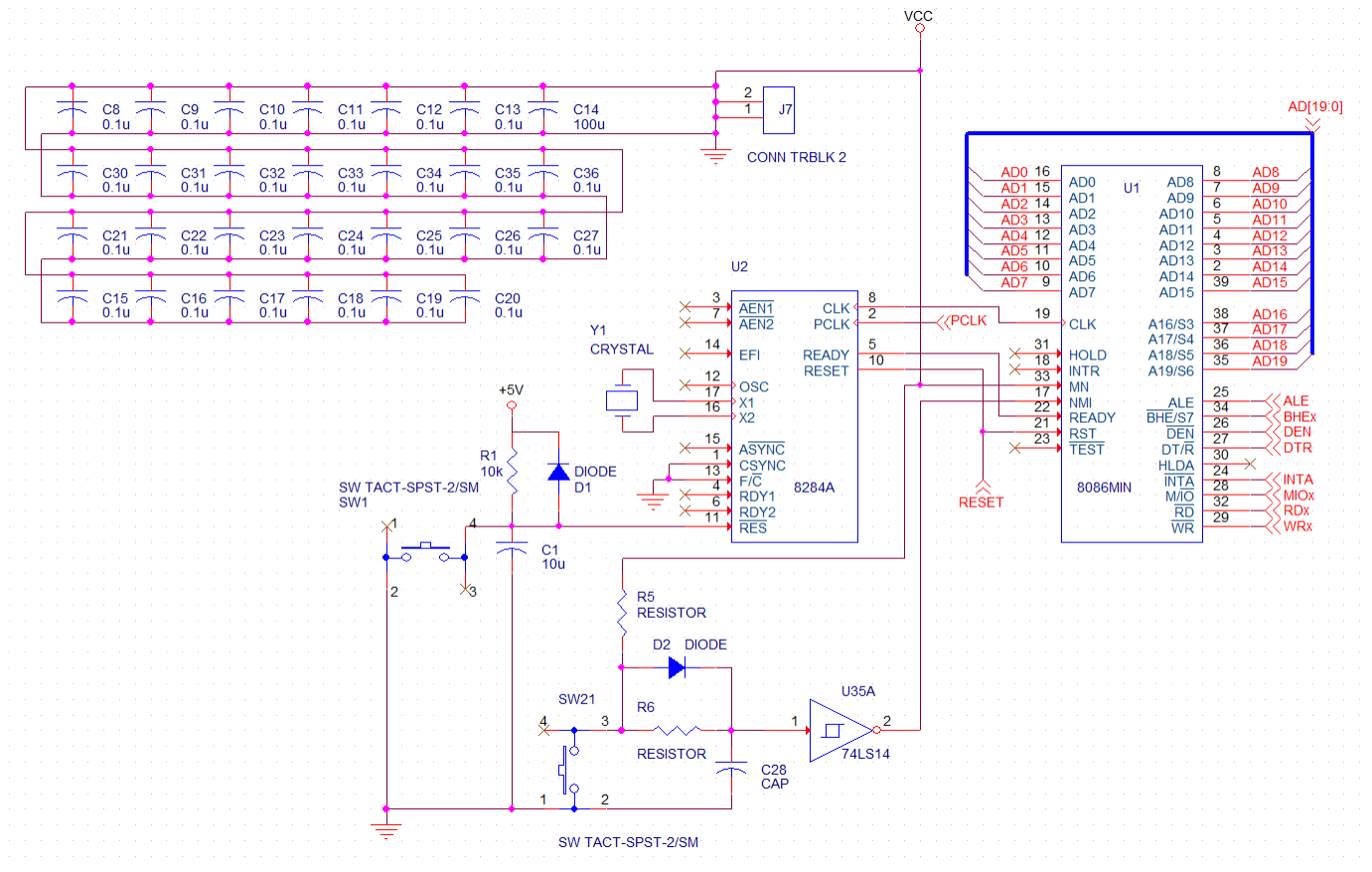


Figure 5: 8086 Interfaced with the 8284A Clock Generator and its Reset RC Push Button Circuit, and the Power Bank of the Board

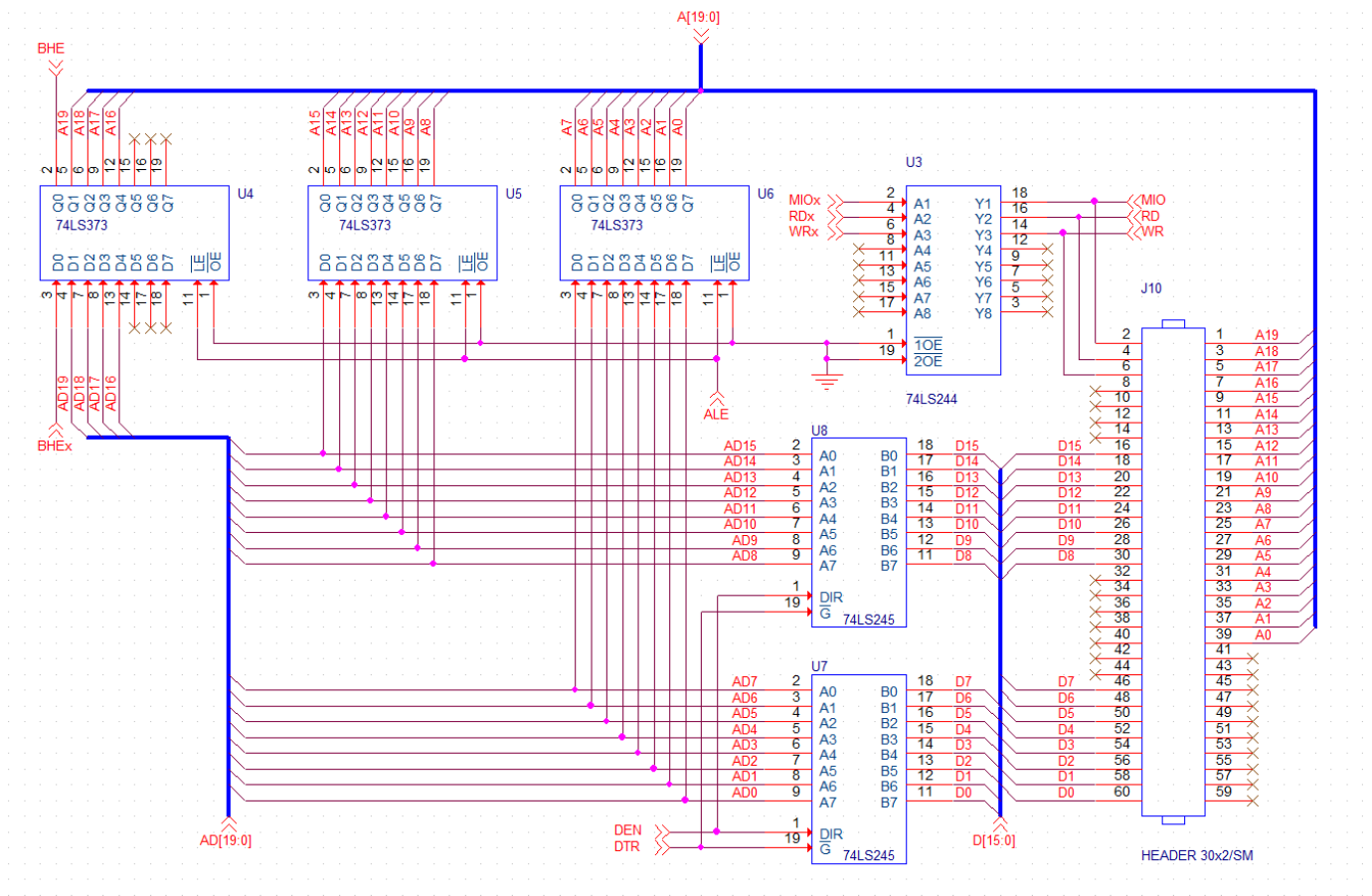


Figure 6: 8086 Demultiplexed with Address and Data Buses Pulled into Headers

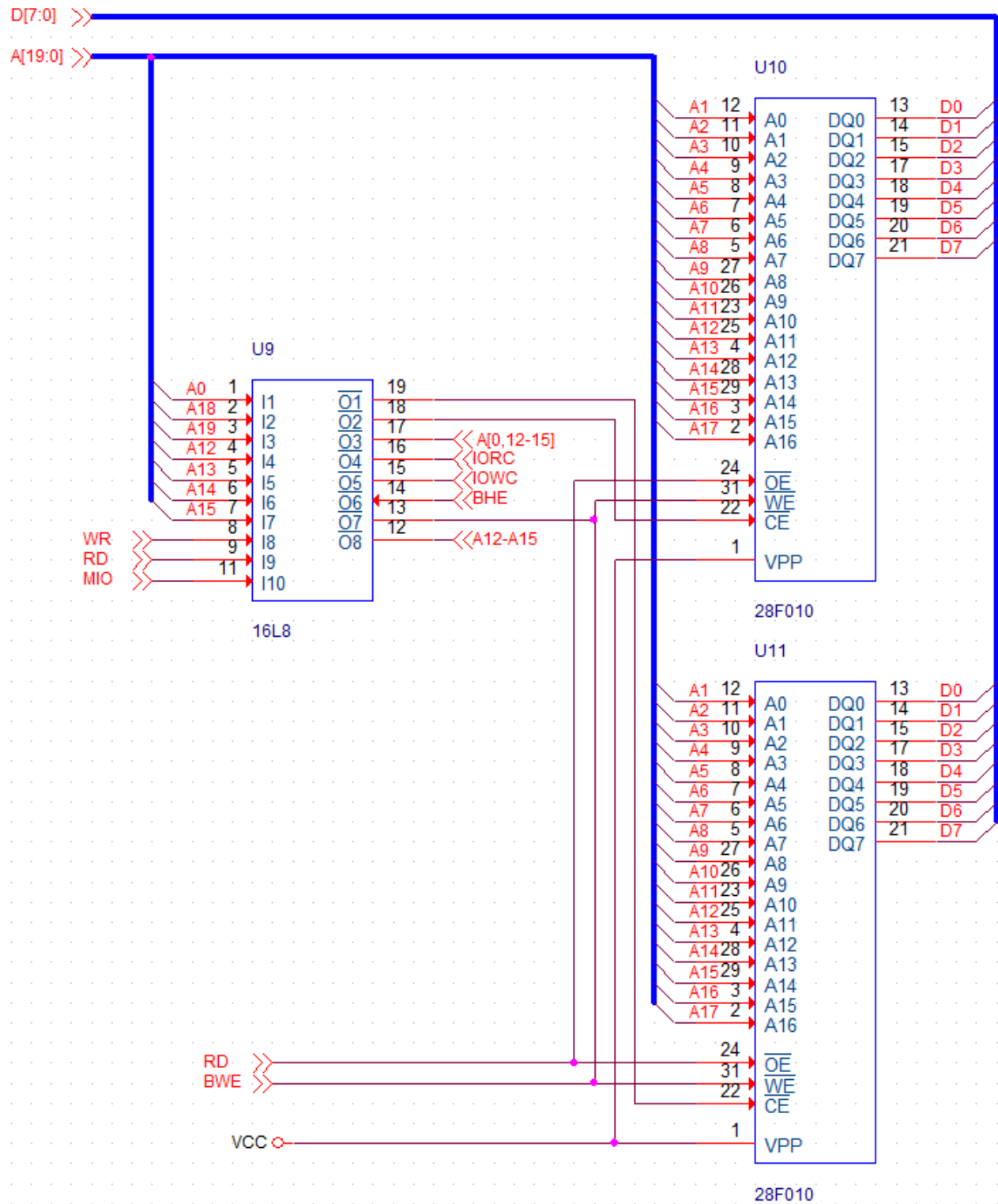


Figure 7: 256 kB of CMOS Flash Memory and 128 kB Static SRAM

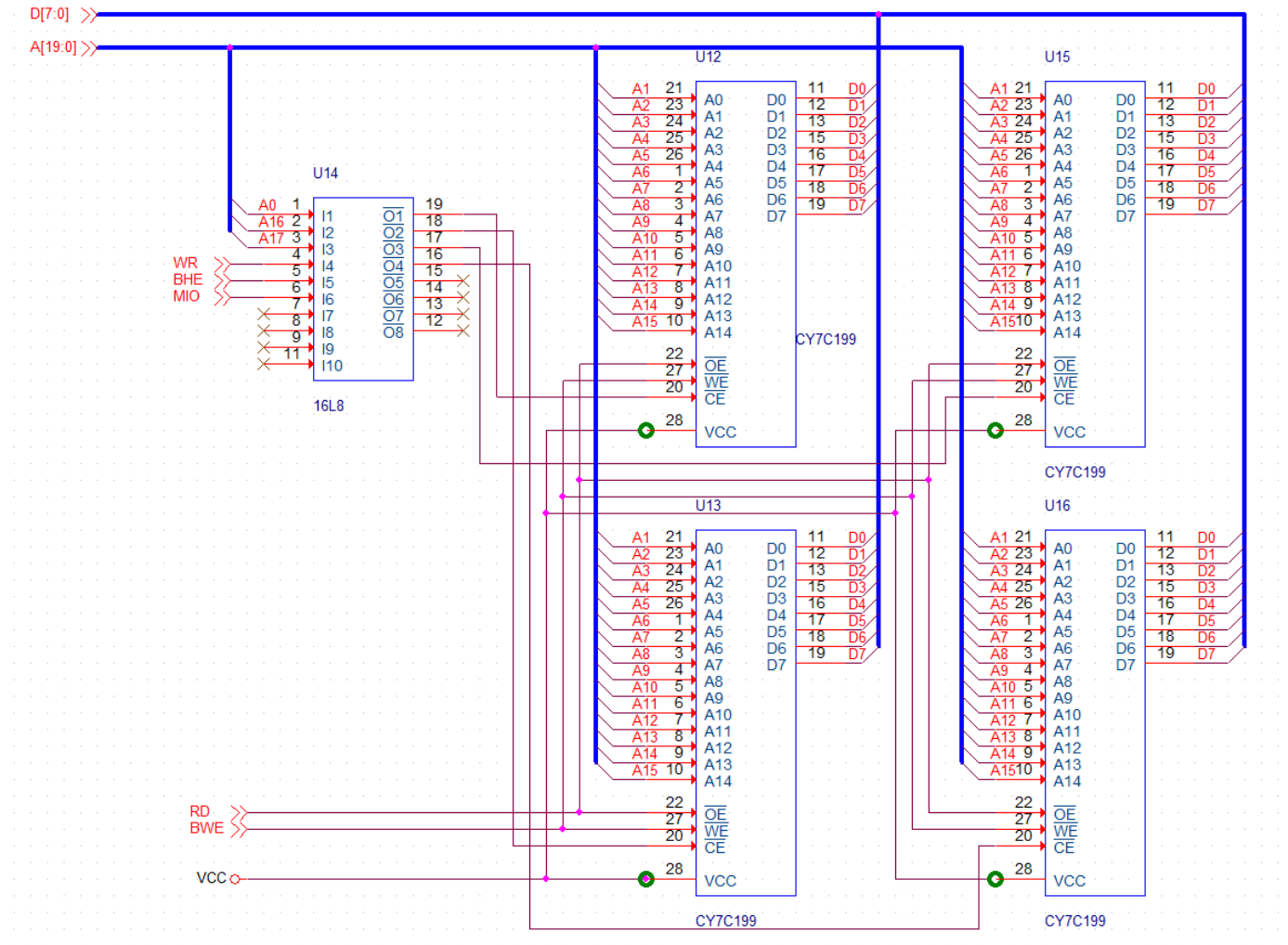


Figure 8: 128 kB Static SRAM

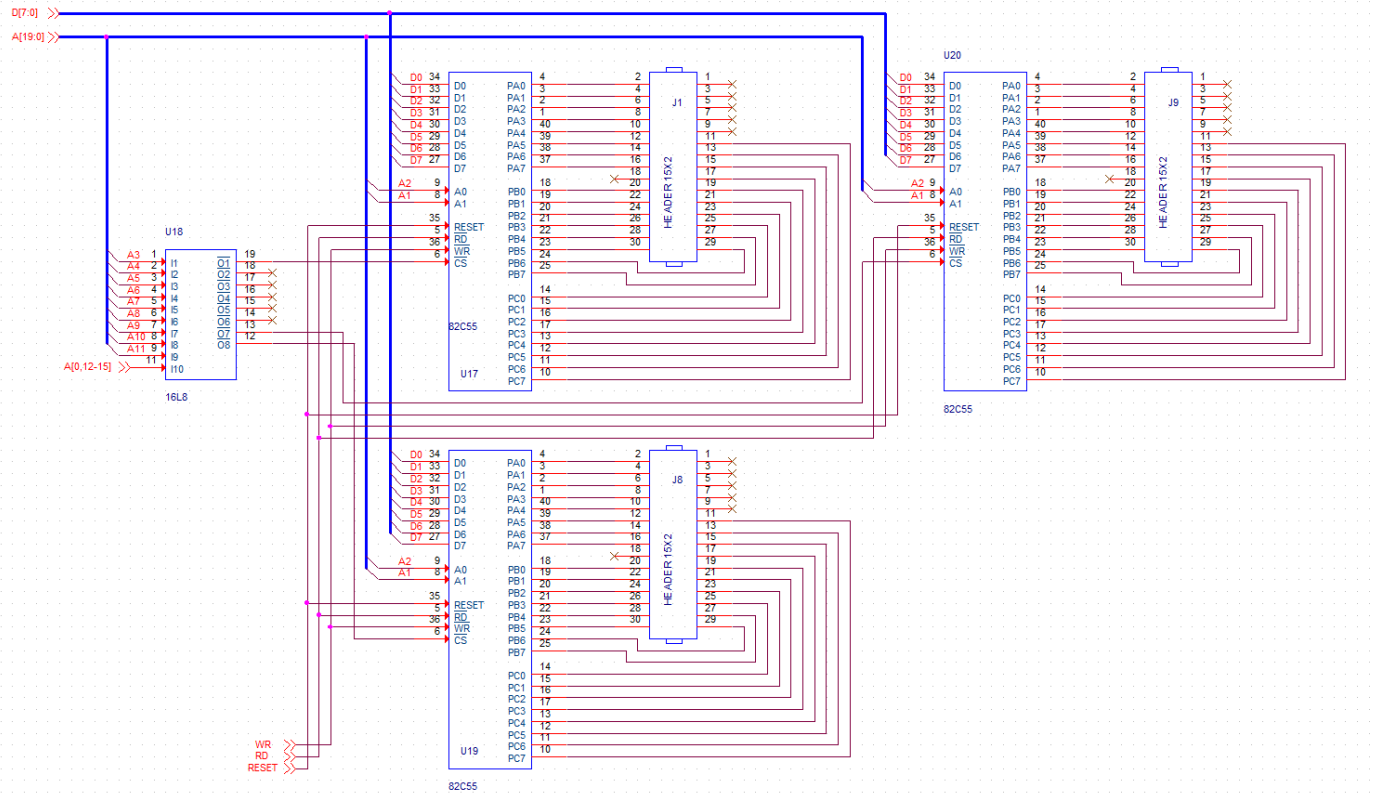


Figure 9: Programmable Peripheral Interface Chips with Port Connections Pulled into Headers

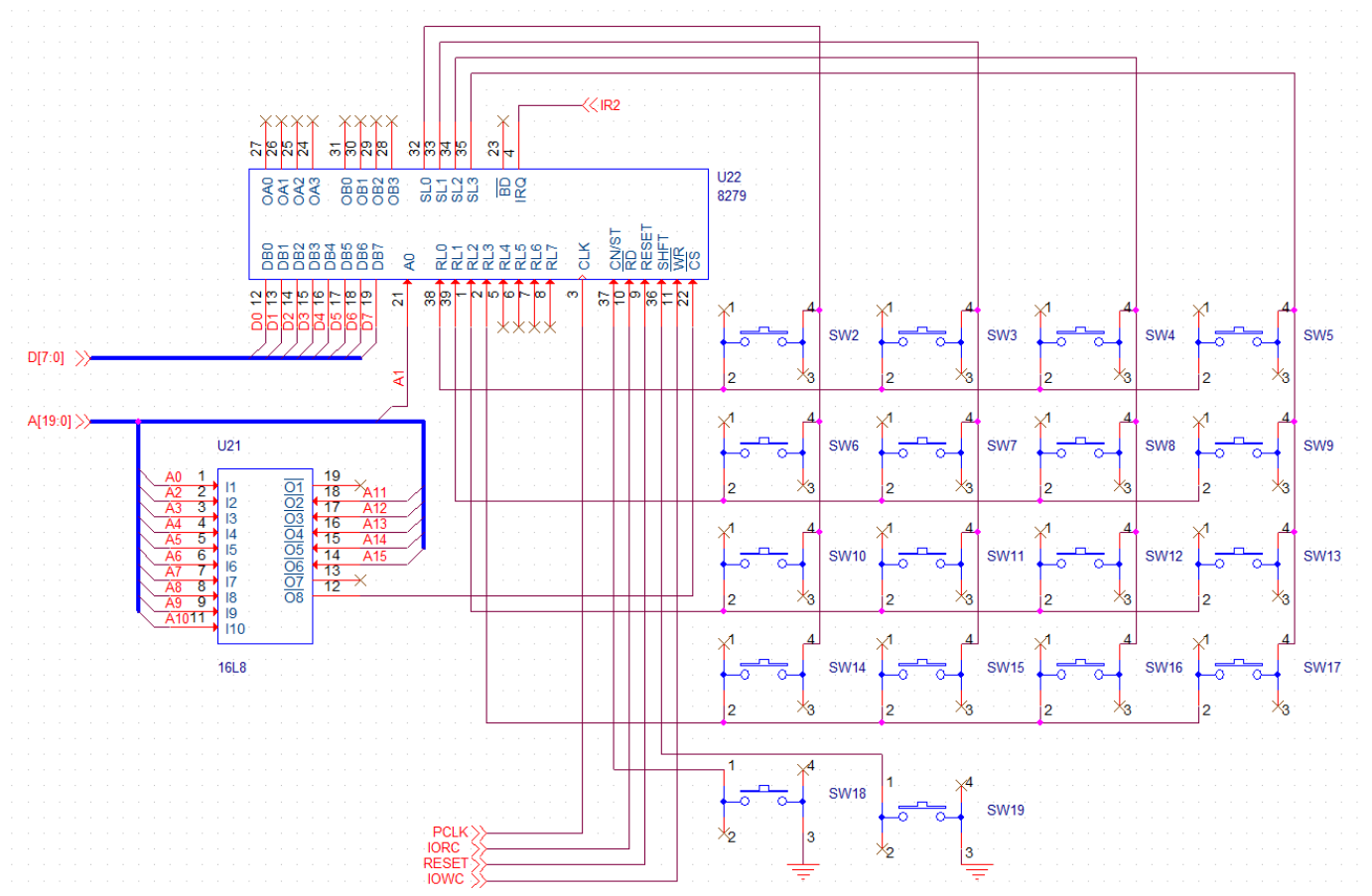


Figure 10: 5×4 Keyboard Matrix

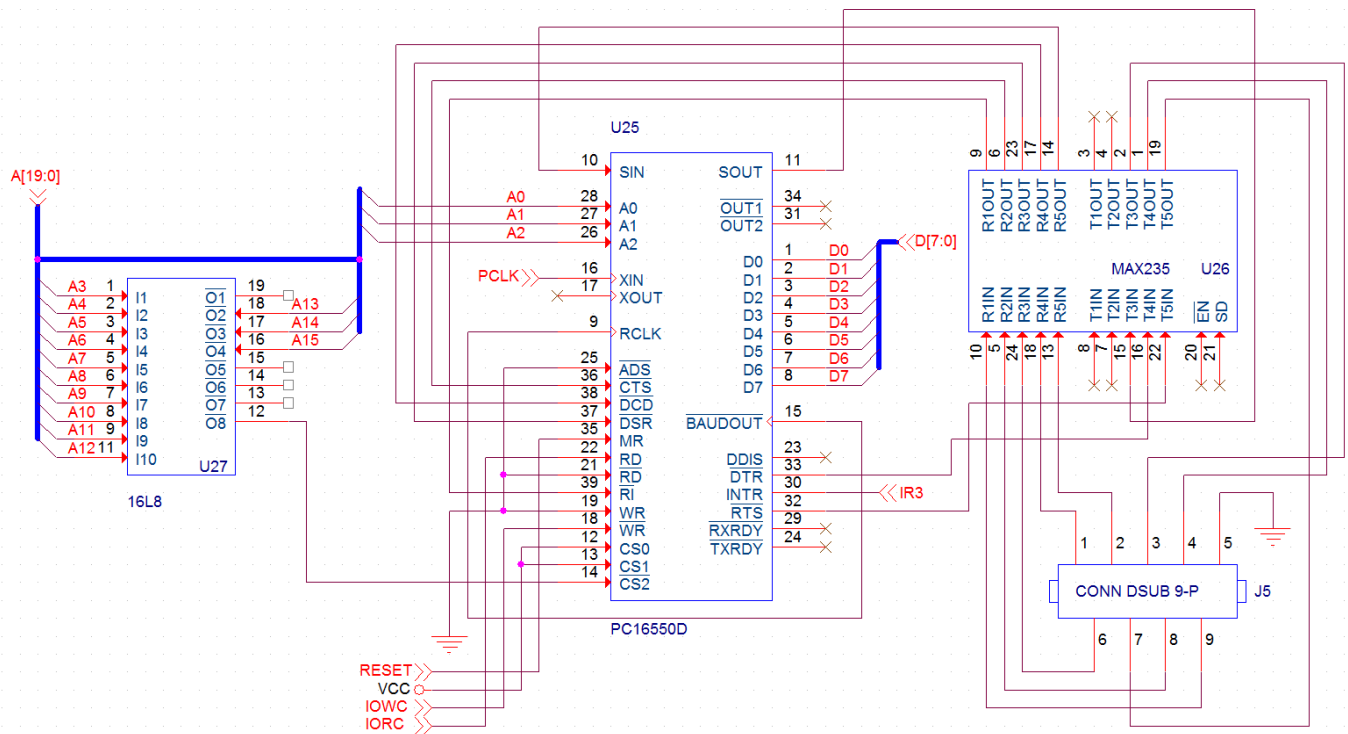


Figure 12: UART Connected for Serial Port Using a Line Driver/Receiver and a DSUB-9 connector

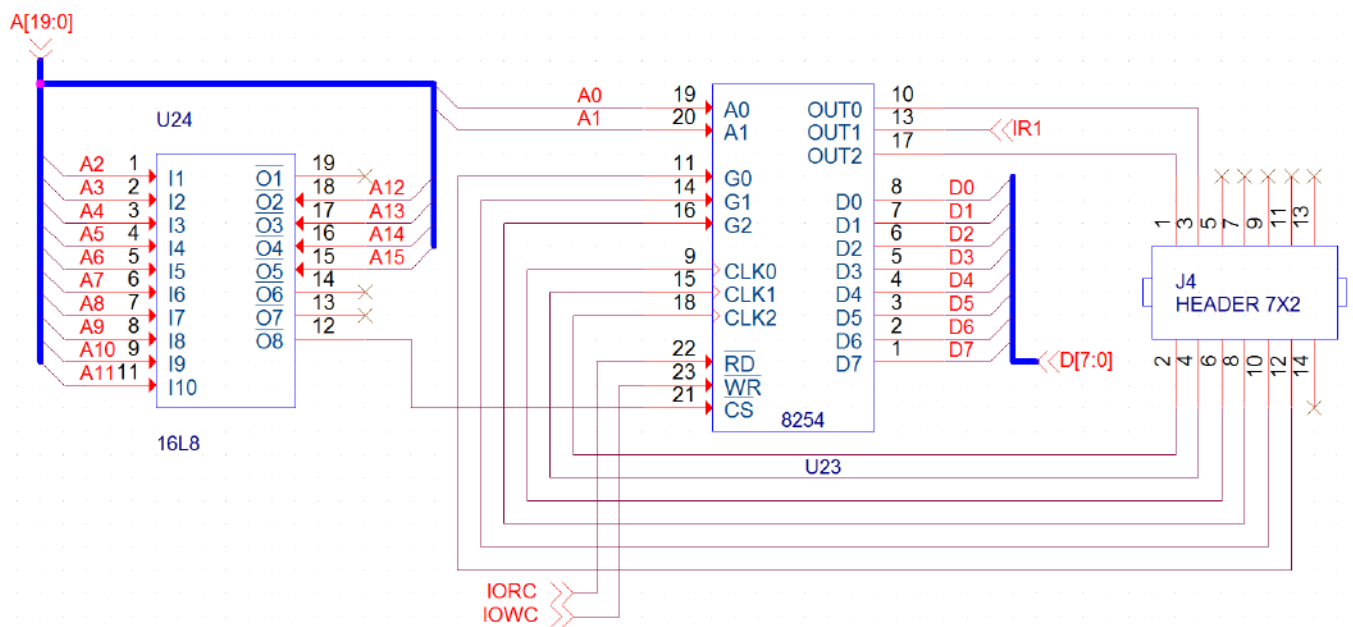
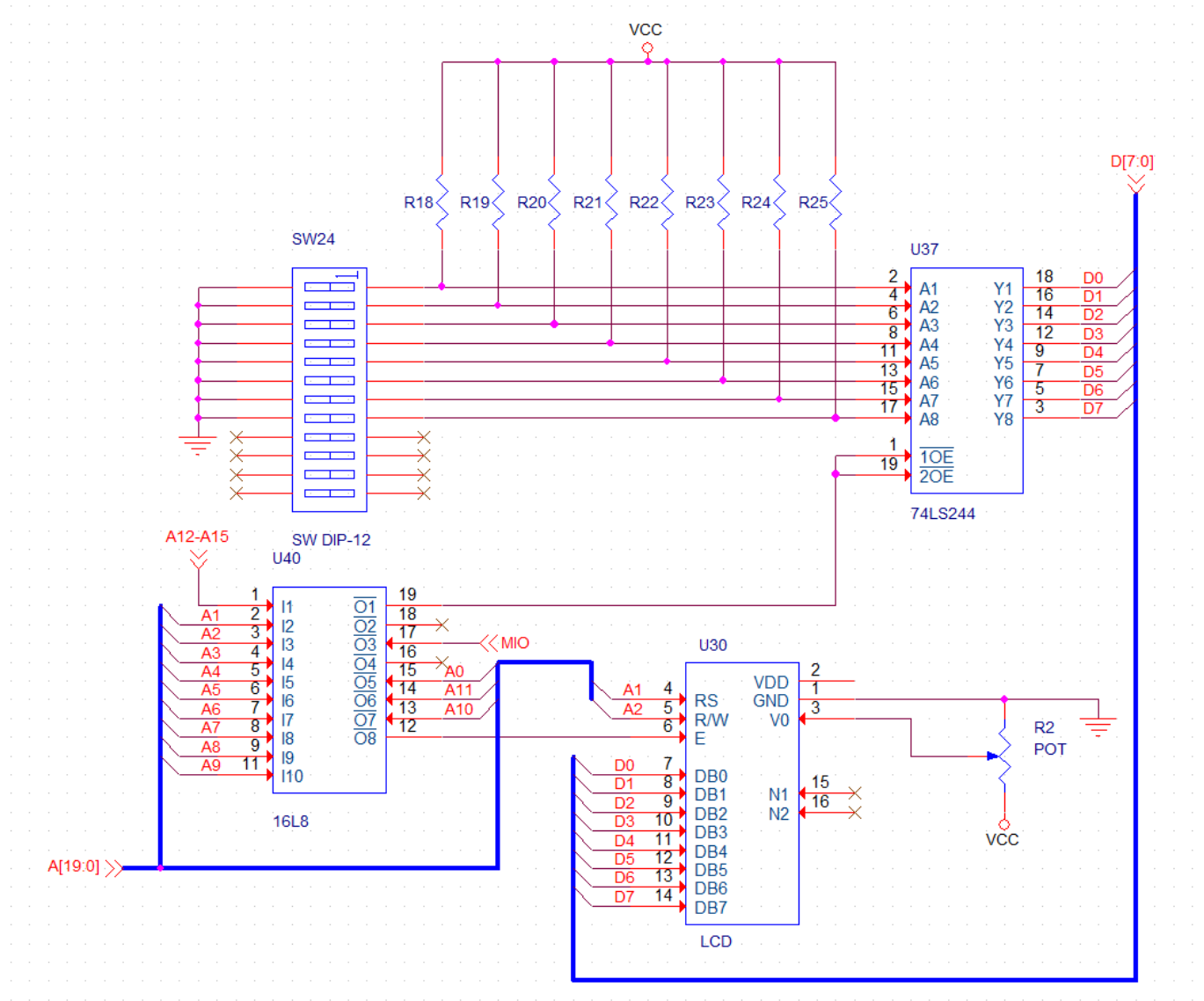


Figure 13: Programmable Interrupt Controller with Headers for External Access

Figure 15: 20 character \times 4 line LCD Display with an Integrated LCD Controller

Appendix B Code Implementations

B.1 Programmable Logic Devices

B.1.1 U9

```
-----  
--  
-- Module: DECODER_U9  
-- Architecture used to decode address and control lines to the CMOS  
-- flash memory  
--  
-----  
  
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U9 is  
    port (  
        A0, A12, A13, A14, A15, A18, A19, WR, RD, MIO, BHE: in STD_LOGIC;  
        O1, O2, A12_A15, A0xA12_A15, IORC, IOWC: out STD_LOGIC  
    );  
end DECODER_U9;  
  
architecture V1 of DECODER_U9 is  
begin  
    O1 <= A19 or A18 or A15 or A14 or A13 or A12 or not(A0);  
    O2 <= A19 or A18 or A15 or A14 or A13 or A12 or A0;  
    A12_A15 <= A15 or A14 or A13 or A12;  
    A0xA12_A15 <= A15 or A14 or A13 or A12 or A0;  
    IORC <= RD or MIO;  
    IOWC <= WR or MIO;  
end V1;
```

B.1.2 U14

```
-----  
--  
-- Module: DECODER_U14  
-- Architecture used to decode address and control lines to the SRAM  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U14 is  
    port (  
        A0, A16, A17, WR, BHE, MIO: in STD_LOGIC;  
        O1, O2, O3, O4: out STD_LOGIC  
    );  
end DECODER_U14;  
  
architecture V1 of DECODER_U14 is  
begin  
    O1 <= not(A17) or not(A16) or A0 or not(WR) or not(BHE) or not(MIO);  
    O2 <= not(A17) or A16 or A0 or not(WR) or not(BHE) or not(MIO);  
    O3 <= A17 or not(A16) or A0 or not(WR) or not(BHE) or not(MIO);  
    O4 <= A17 or A16 or A0 or not(WR) or not(BHE) or not(MIO);  
end V1;
```


B.1.3 U18

```
-----  
--  
-- Module: DECODER_U18  
-- Architecture used to decode address and control lines to the PPI chips  
--  
-----  
  
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U18 is  
    port (  
        A12_A15, A3, A4, A5, A6, A7, A8, A9, A10, A11, MIO: in STD_LOGIC;  
        PPI1, PPI2, PPI3: out STD_LOGIC  
    );  
end DECODER_U18;  
  
architecture V1 of DECODER_U18 is  
begin  
    A12_A15 <= A15 or A14 or A13 or A12;  
    PPI1 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        A7 or A6 or A5 or A4 or  
        not(A3) or not(A0) or not(MIO);  
    PPI2 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        A7 or A6 or A5 or A4 or  
        not(A3) or A0 or not(MIO);  
    PPI3 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        A7 or A6 or A5 or A4 or  
        A3 or not(A0) or not(MIO);  
end V1;
```

B.1.4 U21

```
-----  
--  
-- Module: DECODER_U21  
-- Architecture used to decode address and control lines to the keyboard  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U21 is  
    port (  
        A0, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14,  
        A15: in STD_LOGIC;  
        O8: out STD_LOGIC  
    );  
end DECODER_U21;  
  
architecture V1 of DECODER_U21 is  
begin  
    O8 <= A15 or A14 or A13 or A12 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or not(A5) or not(A4) or  
        A3 or A2 or A0;  
end V1;
```

B.1.5 U24

```
-----  
--  
-- Module: DECODER_U24  
-- Architecture used to decode address and control lines to the  
-- programmable interval counter  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U24 is  
    port (  
        A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14,  
        A15: in STD_LOGIC;  
        O8: out STD_LOGIC  
    );  
end DECODER_U24;  
  
architecture V1 of DECODER_U24 is  
begin  
    O8 <= not(A15) or not(A14) or not(A13) or not(A12) or  
        not(A11) or not(A10) or not(A9) or not(A8) or  
        not(A7) or not(A6) or not(A5) or A4 or  
        not(A3) or A2;  
end V1;
```

B.1.6 U27

```
-----  
--  
-- Module: DECODER_U27  
-- Architecture used to decode address and control lines to the UART  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U27 is  
    port (  
        A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14,  
        A15: in STD_LOGIC;  
        O8: out STD_LOGIC  
    );  
end DECODER_U27;  
  
architecture V1 of DECODER_U27 is  
begin  
    O8 <= A15 or A14 or A13 or A12 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or not(A5) or A4 or  
        A3;  
end V1;
```

B.1.7 U29

```
-----  
--  
-- Module: DECODER_U29  
-- Architecture used to decode address and control lines to the interrupt  
-- controller  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U29 is  
    port (  
        A0, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14,  
        A15: in STD_LOGIC;  
        O8: out STD_LOGIC  
    );  
end DECODER_U29;  
  
architecture V1 of DECODER_U29 is  
begin  
    O8 <= not(A15) or not(A14) or not(A13) or not(A12) or  
        not(A11) or not(A10) or not(A9) or not(A8) or  
        not(A7) or not(A6) or not(A5) or not(A4) or  
        A3 or not(A2);  
end V1;
```

B.1.8 U38

```
-----  
--  
-- Module: DECODER_U38  
-- Architecture used to decode address and control lines to the LEDs  
--  
-----  
  
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U38 is  
    port (  
        A0, A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12_A15,  
        MIO: in STD_LOGIC;  
        O1, O2, O8: out STD_LOGIC  
    );  
end DECODER_U38;  
  
architecture V1 of DECODER_U38 is  
begin  
    A12_A15 <= A15 or A14 or A13 or A12;  
    O1 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or A5 or A4 or  
        not(A3) or not(A2) or not(A1) or A0;  
    O2 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or A5 or A4 or  
        not(A3) or not(A2) or A1 or A0;  
    O8 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or A5 or A4 or  
        not(A3) or not(A2) or not(A1) or not(A0);  
end V1;
```

B.1.9 U40

```
-----  
--  
-- Module: DECODER_U40  
-- Architecture used to decode address and control lines to the LCD and DIP  
-- switches  
--  
-----
```

```
library ieee;  
use ieee.std_logic_1164.all;  
  
entity DECODER_U40 is  
    port (  
        A0, A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12_A15,  
        MIO: in STD_LOGIC;  
        O1, O8: out STD_LOGIC  
    );  
end DECODER_U40;  
  
architecture V1 of DECODER_U40 is  
begin  
    A12_A15 <= A15 or A14 or A13 or A12;  
    O1 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or A5 or A4 or  
        not(A3) or A2 or not(A1) or A0;  
    O8 <= A12_A15 or  
        A11 or A10 or A9 or A8 or  
        not(A7) or not(A6) or A5 or not(A4) or  
        A3 or A0;  
end V1;
```

B.2 Assembly Implementations

B.2.1 LCD

```
; -----  
; Instructions to initialize the LCD controller integrated in the system with  
; the 82C55 Programmable Peripheral Interface (PPI) chip.  
;  
; To assemble and run with the Makefile provided:  
;     make SCRIPT=lcd run  
;  
; -----
```

```
PORTA_ADDR EQU 700H           ; set port addresses  
PORTB_ADDR EQU 701H  
CMD_ADDR   EQU 703H
```

```
; macro to send a command or data to the LCD display
```

```
SEND MACRO PORTA_DATA, PORTB_DATA, DELAY
```

```
    MOV     AL, PORTA_DATA      ; PORTA_DATA to Port A  
    MOV     DX, PORTA_ADDR  
    OUT     DX, AL  
    MOV     AL, PORTB_DATA      ; PORTB_DATA to Port B  
    MOV     DX, PORTB_ADDR  
    OUT     DX, AL  
    OR      AL, 00000100B       ; set E bit  
    OUT     DX, AL              ; send to Port B  
    AND     AL, 11111011B       ; clear E bit  
    NOP  
    NOP                          ; a small delay  
    OUT     DX, AL              ; send to Port B  
    MOV     BL, DELAY           ; BL = delay count  
    CALL    MS_DELAY            ; ms Time Delay  
ENDM
```

```
; Program to initialize the LCD display
```

```
START:
```

```
    MOV     AL, 0FH             ; program the 82C55  
    MOV     DX, CMD_ADDR  
    OUT     DX, AL  
    MOV     AL, 0  
    MOV     DX, PORTB_ADDR      ; clear Port B  
    SEND    30H, 2, 16          ; send 30H for 16 ms  
    SEND    30H, 2, 5           ; send 30H for 5 ms  
    SEND    30H, 2, 1           ; send 30H for 1 ms  
    SEND    38H, 2, 1           ; send 38H for 1 ms  
    SEND    8, 2, 1             ; send 8 for 1 ms  
    SEND    1, 2, 2             ; send 1 for 2 ms  
    SEND    0CH, 2, 1           ; send 0CH for 1 ms  
    SEND    6, 2, 1             ; send 6 for 1 ms
```


B.2.2 Programmable Peripheral Interface

```
; -----  
; Instructions to demonstrate an example interface with the 82C55 programmable  
; peripheral interface. This script reads data derived from a control register  
; and writes it to port B.  
;  
; To assemble and run with the Makefile provided:  
;     make SCRIPT=ppi run  
;  
; -----  
  
CTRL_BYTE EQU 0091H           ; set control register with:  
                               ; PA=IN, PB=OUT, PC0-PC3=IN, PC4-PC7=OUT,  
                               ; MODE=0  
  
; Program to read data from port A and write to port B using port addresses  
; 300H-303H  
START:  
    MOV     AL, CTRL_BYTE      ; grab the control byte data  
    MOV     DX, 303H  
    OUT     DX, AL  
    MOV     DX, 300H  
    IN      AX, DX  
    MOV     DX, 301H  
    OUT     DX, AX
```

B.2.3 Keyboard

```
; -----  
; Instructions to initialize the keyboard controller integrated in the system  
; with the 82C55 Programmable Peripheral Interface (PPI) chip.  
;  
; To assemble and run with the Makefile provided:  
;     make SCRIPT=keyboard run  
;  
; -----  
  
KEYBRD_ADDR EQU 00F2H           ; set 8279 addresses  
  
; Program to initialize the keyboard with the 8279  
START:  
    MOV     DX, KEYBRD_ADDR      ; point to 8279 command address  
    MOV     AL, 00000011B        ; set mode for left entry, 8-digit display,  
                                ; decoded scan, N-key rollover  
    OUT     DX, AL               ; send to 8279  
    MOV     AL, 3EH              ; clock word for divide by 30  
    OUT     DX, AL  
    MOV     AL, COH              ; clear display to display all zeroes
```

B.2.4 Programmable Interval Timer

```
; -----  
; Instructions to demonstrate an example interface with the 8254 programmable  
; interval timer. This script sends a control byte to the control register.  
;  
; To assemble and run with the Makefile provided:  
;     make SCRIPT=pit run  
;  
; -----  
  
; Program to send a control byte to the control register  
START:  
    MOV     AL, 01110111B      ; counter 1, mode 3, BCD  
    OUT     FFEH, AL          ; send to control register
```

B.2.5 Universal Asynchronous Receiver/Transmitter

```
; -----  
; Instructions to demonstrate an example interface with the 8254 UART with a  
; baud rate of 2400, 5 data bits, 1.5 stop bit parity and reads the bytes from  
; receive FIFO.  
;  
; To assemble and run with the Makefile provided:  
;     make SCRIPT=uart run  
;  
; -----
```

```
LINE      EQU 0F3H          ; 16550 line register  
LSB        EQU 0F0H          ; 16550 baud divisor LSB  
MSB        EQU 0F1H          ; 16550 baud divisor MSB  
FIFO       EQU 0F2H          ; 16550 FIFO register
```

```
INIT PROC NEAR
```

```
    MOV     AL, 10011100      ; enable baud rate divisor  
    OUT     LINE, AL  
    MOV     AL, 50H           ; program baud rate 2400  
    OUT     LSB, AL  
    MOV     AL, 00H  
    OUT     MSB, AL  
    MOV     AL, 00011100B     ; program 5 data bits, even parity, 1 stop  
    OUT     LINE, AL  
    MOV     AL, 00000111B     ; enable transmitter and receiver  
    OUT     FIFO, AL
```

```
    RET
```

```
INIT ENDP
```

Appendix C PCB Layouts

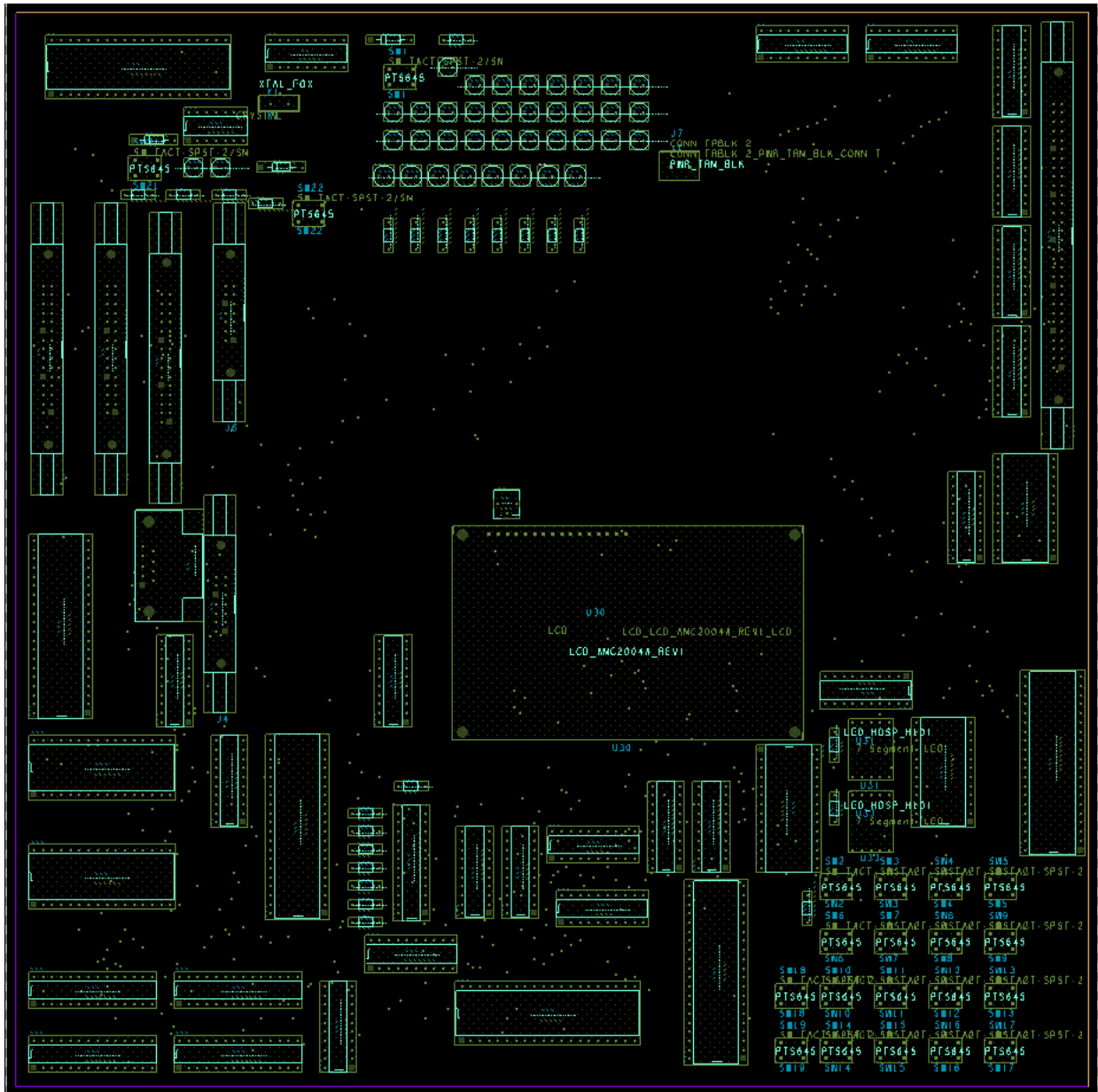


Figure 16: Final PCB Layout Showing Only the Components

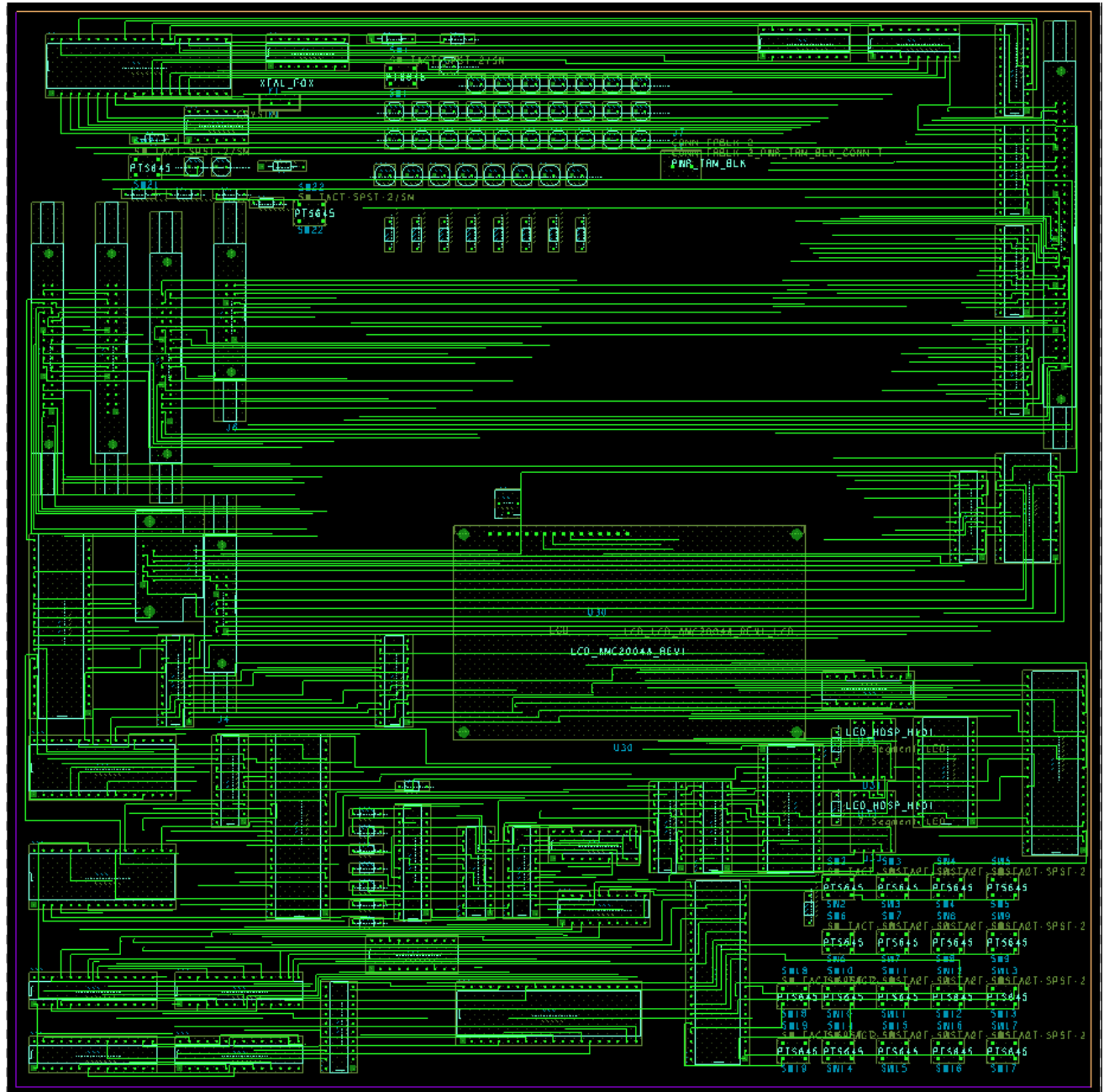


Figure 17: Final PCB Layout with only the Top Layer Activated

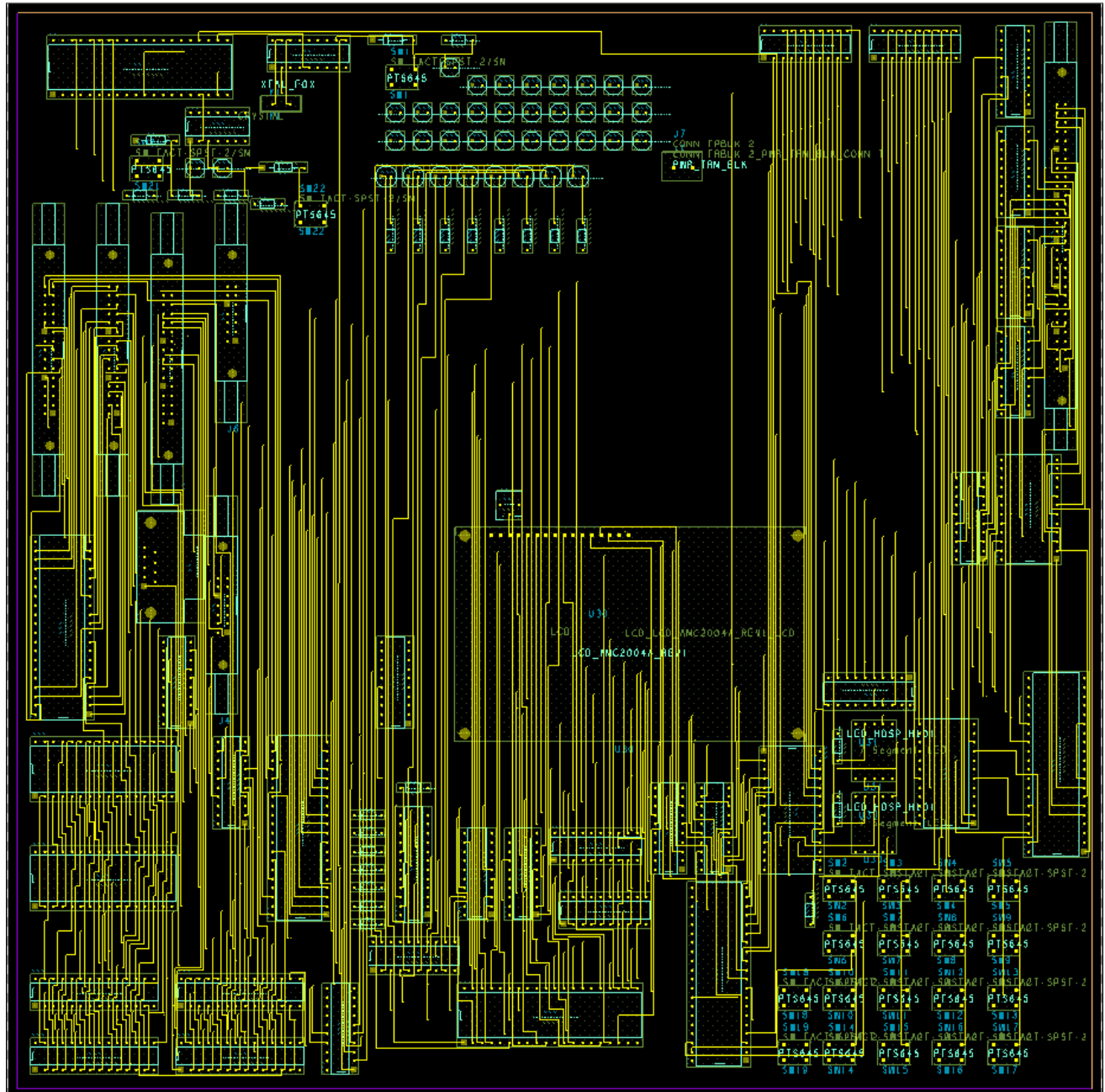


Figure 18: Final PCB Layout with only the Bottom Layer Activated

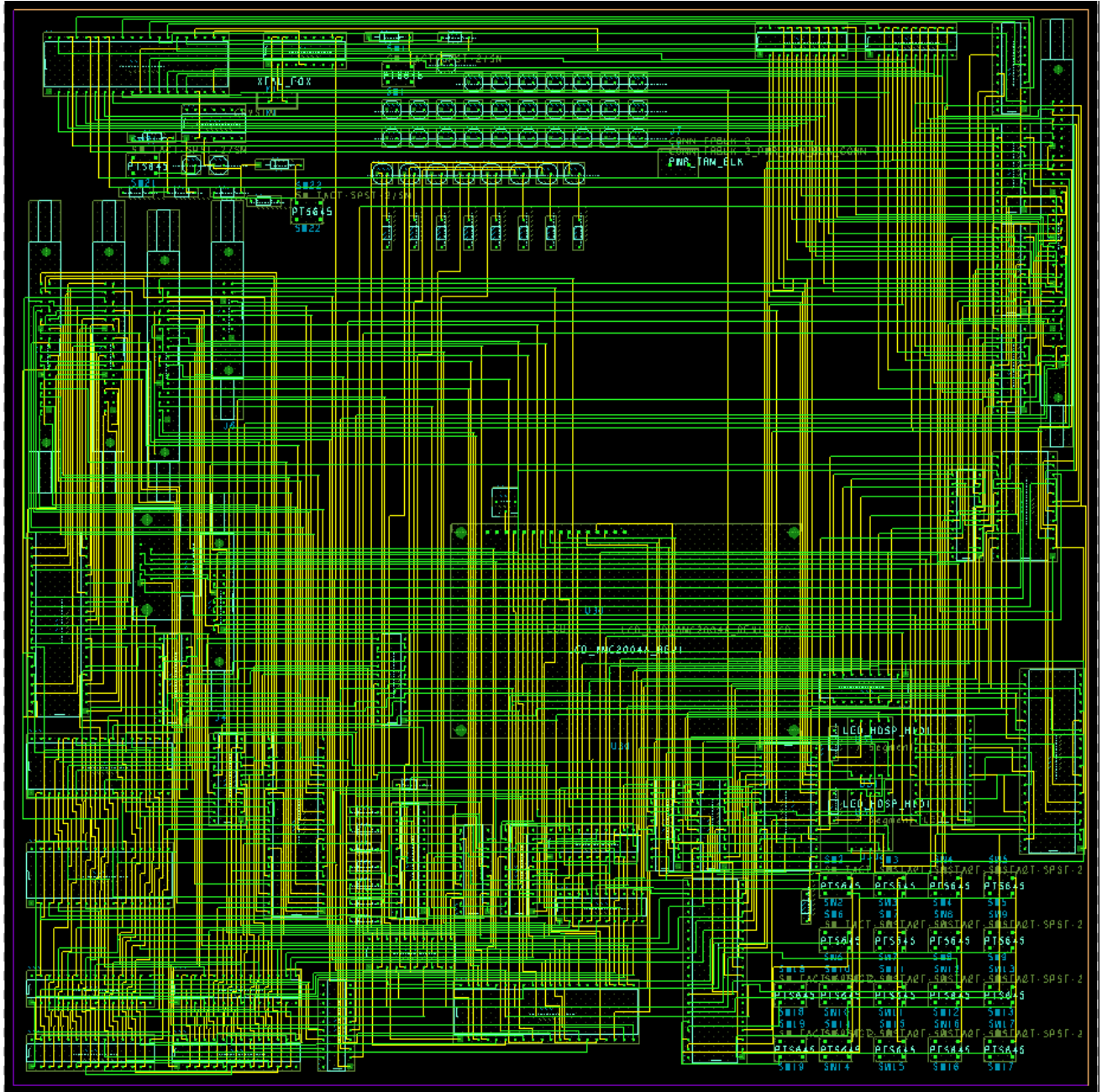


Figure 19: Final PCB Layout with all Layers Activated

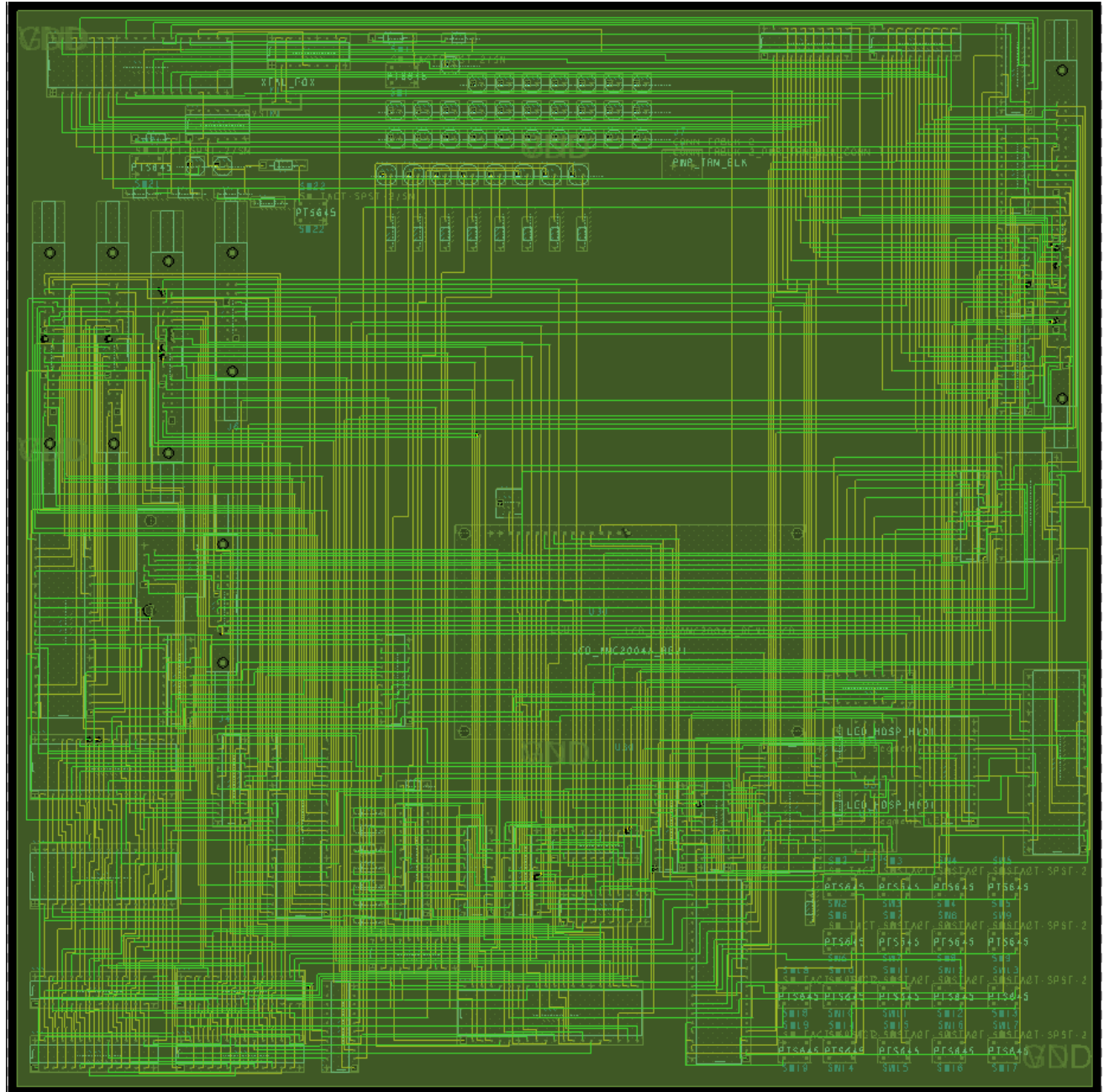


Figure 20: Final PCB Layout with all Layers Activated, including Power and Ground

Appendix D Bill of Materials

Amount	Part	Description
1	C1	10u
26	C8,C9,C10,C11,C12,C13,C15,C16, C17,C18,C19,C20,C21,C22,C23,C24,C25, C26,C27,C30,C31,C32,C33,C34,C35,C36	0.1u
1	C14	100u
2	C28,C29	CAP
3	D1,D2,D3	DIODE
8	D4,D5,D6,D7,D8,D9,D10,D11	LED
3	J1,J8,J9	HEADER 15X2
2	J4,J6	HEADER 7X2
1	J5	CONN DSUB 9-P
1	J7	CONN TRBLK 2
1	J10	HEADER 30x2/SM
11	R1,R3,R4,R18,R19,R20,R21,R22, R23,R24,R25	10k
1	R2	POT
13	R5,R6,R7,R8,R9,R10,R11,R12,R13, R14,R15,R16,R17	RESISTOR
3	SW1,SW21,SW22	SW TACT-SPST-2/SM
18	SW2,SW3,SW4,SW5,SW6,SW7,SW8,SW9, SW10,SW11,SW12,SW13,SW14,SW15,SW16,SW17, SW18,SW19	SW TACT-SPST-2
1	SW24	SW DIP-12
1	U1	8086MIN
1	U2	8284A
2	U3,U37	74LS244
3	U4,U5,U6	74LS373
2	U7,U8	74LS245
9	U9,U14,U18,U21,U24,U27,U29,U38,U40	16L8
2	U10,U11	28F010
4	U12,U13,U15,U16	CY7C199
3	U17,U19,U20	82C55
1	U22	8279
1	U23	8254
1	U25	PC16550D
1	U26	MAX235
1	U28	8259A
1	U30	LCD
2	U31,U33	7 Segment LED
2	U32,U34	74ALS374
1	U35	74LS14
1	U39	74LS374
1	Y1	CRYSTAL

References

- [1] Address Bus, Data Bus, Control Bus
<http://gradestack.com/Microprocessors-and/Architecture-of-8086-and/Address-Bus-Data-Bus-19317-3912-38171-study-wtw>
- [2] Programmable Array Logic
<https://www.electrical4u.com/programmable-array-logic/>