

FPGA : A Guide to Interfacing Peripherals

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Abstract— FPGAs (Field Programmable Gate Arrays) are the heart of Embedded Systems. With the advantages of parallel processing and full customization while designing code for a digital hardware using VHDL(Very High speed Integrated Circuits Hardware Description Language) or Verilog, FPGAs have captured the Embedded market in their full stream. In this paper, we will understand the interfacing concepts regarding interfacing ADC0809CCN, LCD JHD162A & 7-Segment Display with XILINX SPARTAN 3e FPGA (IC XC3S500E-PQG208).

Index Terms— FPGA, VHDL, ADC (IC 0809CCN) [Analog to Digital Converter], LCD (JHD 162A) [Liquid Crystal Display], 7SEGMENT DISPLAY.

I. INTRODUCTION

Embedded Systems occupy a central role in any practical project development related to all the core domains of engineering be it Mechanical, Civil, Mining or Electrical. The brain of an embedded system comprises of microprocessors, DSP processors or FPGAs (Field Programmable Gate Arrays) / CPLDs (Complex Programmable Logic Devices). With the advent of Programmable Logic Devices / Programmable Gate Arrays in 1980s , FPGAs are all set to take over microprocessors & DSP processors in the area of parallel processing with the Speed , Cost & Area constraints being handled in an efficient manner as compared to microprocessors & DSP processors. Keeping this view in mind, the paper brings forward the peripheral concepts of interfacing devices with FPGA with practical examples of interfacing an ADC (IC 0809CCN) , LCD (JHD162A) & 7-Segment Display with XILINX SPARTAN 3e FPGA (IC XC3S500E-PQG208).

II. INTERFACING DEVICES

A. ADC (Analog To Digital Converter):

Analog to Digital converter is one of the basic devices that behaves as an interpreter between the practical analog world and the virtual digital world. Any physical parameter/variable like pressure, humidity, temperature, distance (height/length), etc. can be converted into its electrical counterpart like voltage or current [via a Transducer] & can then be sensed [via a Sensor], further which ought to be converted to a digital signal either for storage , transmission or processing purposes. An ADC comes in handy during such applications & to be more precise, an ADC is an integral part of almost every practical hardware project which desires to integrate the environmental conditions into the very working of that practical hardware project.

a. Importance of ADC Interface :

- Any practical signal is analog in nature
- For taking feedback from natural/practical signals
- For making an interface with the world or for talking/communicating with the world

- When a practical system has SENSE ORGANS, ADC comes in handy
- b. *Types of ADC:*
- Flash ADC
 - Dual Slope ADC
 - Successive Approximation ADC
 - Sigma Delta ADC

c. *Working of ADC:*

Successive Approximation Type of ADC :

This type of ADC has a resistive voltage divider kind of DAC built-in the structure. ADC IC0809CCN is used in experimentation, which is an eight-channel Successive Approximation type of ADC having a conversion time of 100 μ sec.s and typical clock frequency of 640 kHz. The control / data signals of ADC IC0809CCN are as follows:

- i] START : It is an input control signal to start the conversion of analog signal into eight-bits of digital data.
- iii] A2A1A0 : It is an input control signal which selects one out of eight analog channels.
- ii] ALE : It is an input control signal called as address latch enable; which confers that the address on A2A1A0 pins remains same for the entire conversion time period.
- iv] EOC : It is an output control signal called end of conversion which rises to HIGH state when the conversion procedure is finished.
- v] OE : It is an input control signal called output enable which has to be risen to a HIGH state to collect the 8-bits of digital data from D7D6D5D4D3D2D1D0 pins.
- vi] D7D6D5D4D3D2D1D0 : These are output data lines called 8-bits digital data signals, which are produced after an analog signal is converted to its digital equivalent.

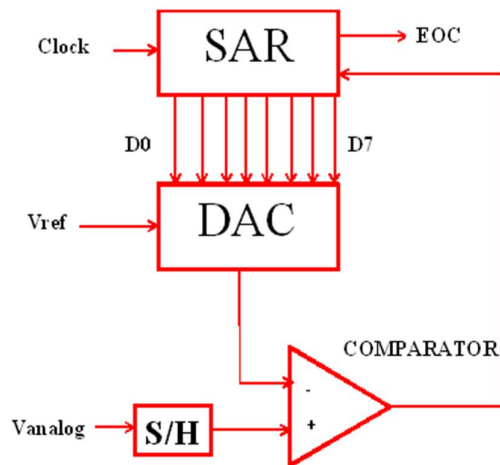


Fig 1 : Successive Approximation Type of ADC[IC 0809CCN]

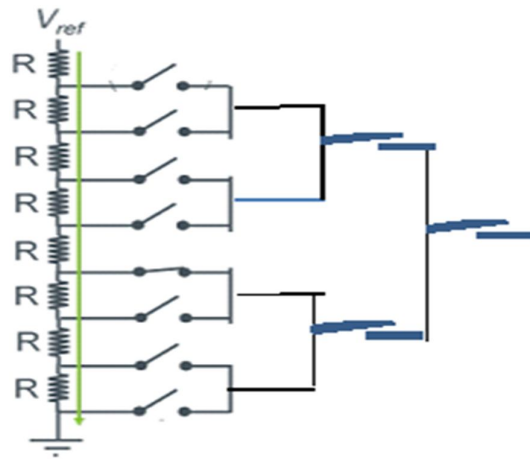


Fig 2 : Resistive Divider DAC

d. *Calculation For ADC Output:*

For Example : Analog Volt I/P = 4.5 Volts

Step : 1] Assuming : 3bit ADC ; Assuming : $V_{ref} = 5$ Volts

Step : 2] 1st SAR approximation : D2D1D0 = 100 ; DAC equivalent for SAR =100 is 2.5 Volts
Output of COMPARATOR=1; D2 =1 (final)

Step : 3] 2nd SAR approximation : D2D1D0 = 110; DAC equivalent for SAR =110 is 3.75 Volts
Output of COMPARATOR=1; D1 =1 (final)

Step : 4] 3rd SAR approximation : D2D1D0 = 111; DAC equivalent for SAR =111 is 4.375 V
Output of COMPARATOR=1; D0 =1 (final)

Step : 5] Final Decimal Equivalent : D2D1D0 =111

e. *Timing Diagram of ADC :*

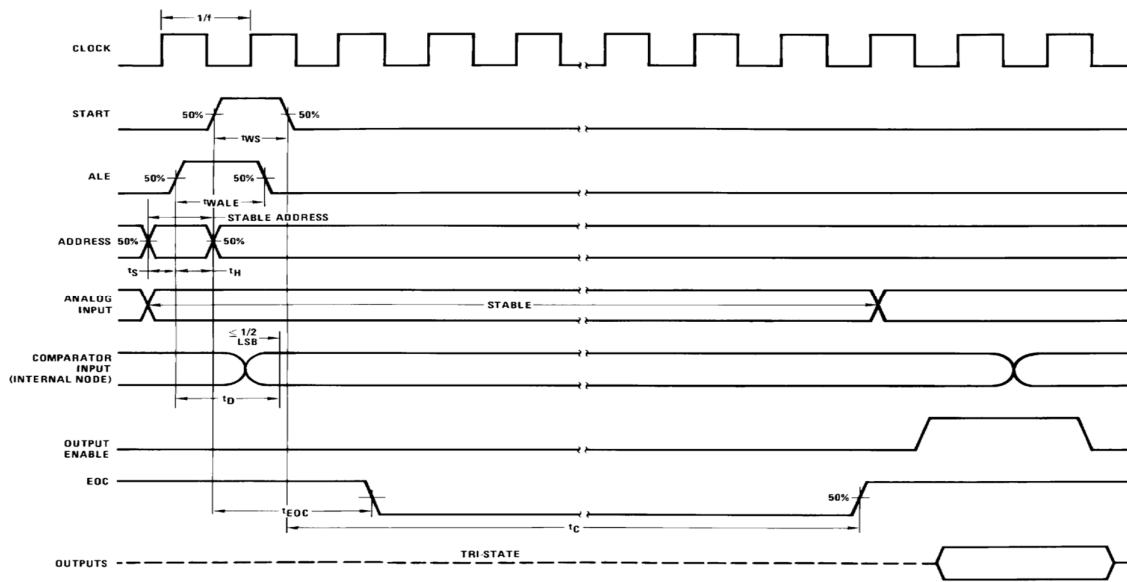


Fig 3 : Timing Diagram of ADC IC 0809CCN

f. VHDL Code For ADC Interface :

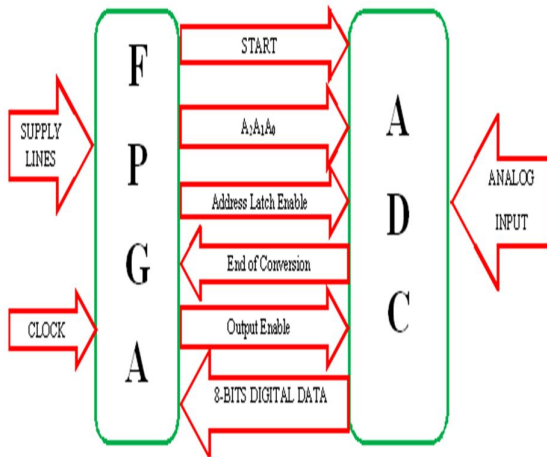


Fig 4 : Block Diagram For ADC Interface

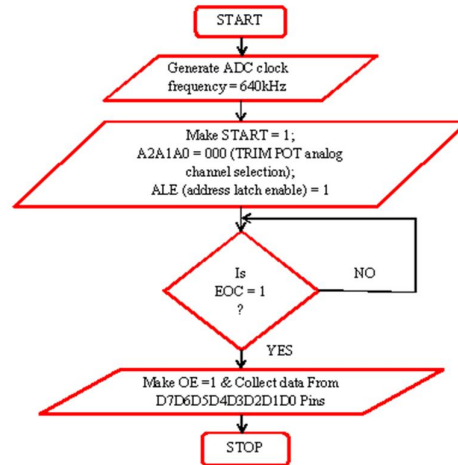


Fig 5 : Flowchart For ADC Interface

B. LCD (Liquid Crystal Display)

LCD IC JHD162A is used for experimentation. It is a 16x2 display, i.e. sixteen (16) number of columns & two (2) number of rows therefore can display thirty-two (32) characters at a time. The control/data signals of LCD IC JHD162A are as follows:

- i] Read/Write : It is an input control signal to either read from or write to the 8-data lines $D_0D_1D_2D_3D_4D_5D_6D_7$ of LCD IC.
- ii] Enable : It is an input control signal used to enable the LCD functioning.
- iii] Register Select : It is an input control signal used for selecting either the data register or the control register.
- iv] Contrast Control : It is used for controlling the contrast of the LCD IC.
- v] $D_0D_1D_2D_3D_4D_5D_6D_7$: These are eight data lines used to either write the control bits to the control register or the data bits to the data register.

a. VHDL Code for ADC Interface (LCD Display IC JHD162A)

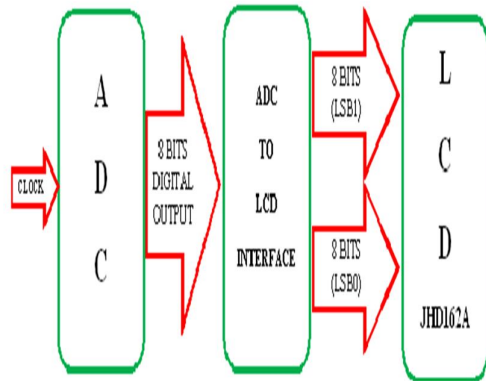


Fig 6 : Block Diagram [ADC & LCD]

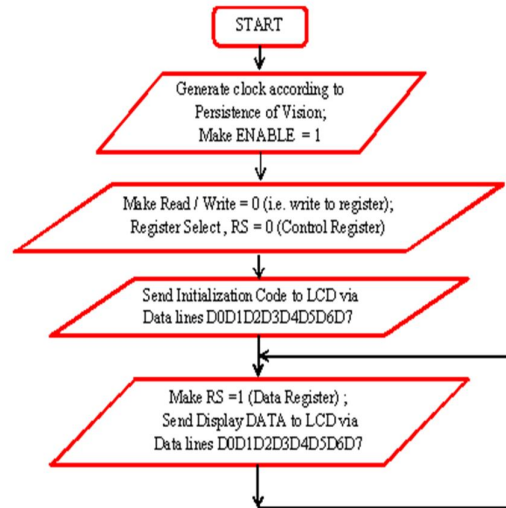


Fig 7: Flowchart [ADC & LCD]

C. Seven Segment Display

The seven segment display IC used in experimentation is a common Anode type. There are eight LEDs arranged in such a fashion so that we can display all the numbers & almost all alphabets with the help of the seven segment display IC. When using more than one 7-segment display, we have to take help of multiplexing concept for displaying the alpha-numeric digits on the seven segment display IC. Persistence of Vision concept comes into handy while multiplexing two or more than two 7-segment displays. The control/data signals of 7-segment display are as follows:

- Anode Enable : It is an input signal used for switching on all the LEDs, i.e. enabling the anode of the LEDs since anode terminal of all the LEDs are tied together.
- abcdefg & dp : These are eight data input lines for accepting the bit pattern to be displayed. a,b,c,d,e,f are the line segment LEDs & dp is the dot LED for representing a decimal point.

a. VHDL Code for ADC Interface (7segment Display)

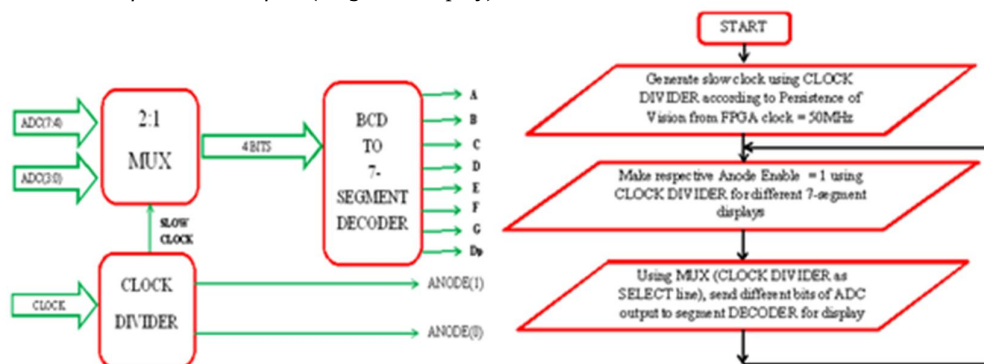


Fig 8 : Block Diagram [ADC & 7-segment Display]

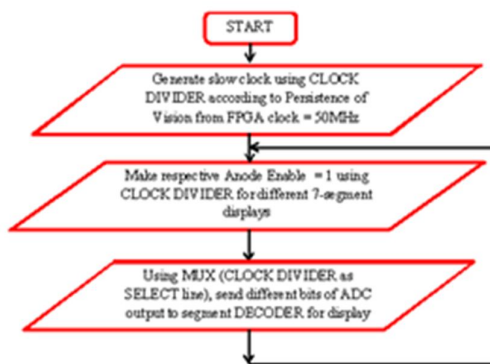


Fig 9: Flowchart [ADC & 7-segment Display]

III. EXPERIMENTAL RESULTS

The interfacing of XILINX FPGA IC Spartan3e XC3S500E-PQG208 has been carried out with the following ICs and the experimental results are shown thereafter. The clock frequency used for XILINX FPGA XC3S500E-PQG208 is 50MHz. The IC packaging used for FPGA is Quad Flat Package with 208 I/O pins.

- ADC IC 0809CCN
- LCD IC JHD162A

iii. 7-SEGMENT DISPLAY IC

A. ADC (Analog To Digital Converter)



Figure 10. ADC Interfacing board

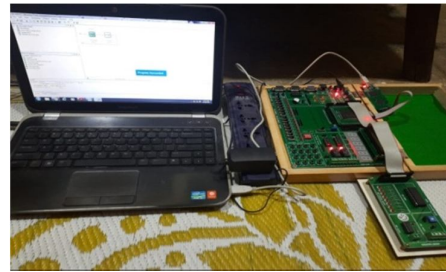


Figure 11. Interfacing of FPGA with ADC

The XILINX ISE 11 (Project Navigator) is used to enter, edit, compile & synthesize the VHDL code for ADC interface. XILINX iMPACT 11 is used for programming the FPGA with the ADC bit file which is an equivalent bit conversion from the ADC VHDL code.

a. Hardware Result: Interfacing FPGA to ADC (channel 0 = TRIM POT)



Fig 12 : ADC Output = F2 H



Fig 13: ADC Output = E5 H



Fig 14 : ADC Output = BA H

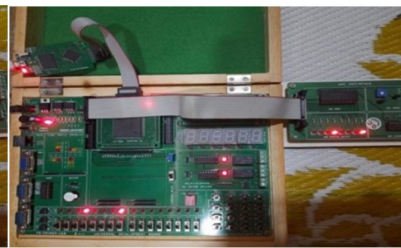


Fig 15: ADC Output = 11 H

b. ADC Output (TRIM POT) : Data Table

TABLE 1 : DATA TABLE OF ADC OUTPUT

Serial No.	Digital Data	Decimal Equivalent	Analog Input Voltage	Serial No.	Digital Data	Decimal Equivalent	Analog Input Voltage
1.	4F H	79	1.54 Volts	8.	5D H	85	1.66 Volts
2.	A7 H	167	3.26 Volts	9.	D6 H	214	4.18 Volts
3.	FF H	255	4.98 Volts	10.	3E H	62	1.21 Volts
4.	A3 H	163	3.18 Volts	11.	6C H	108	2.11 Volts
5.	2B H	43	0.84 Volts	12.	AA H	170	3.32 Volts
6.	35 H	53	1.04 Volts	13.	88 H	136	2.66 Volts
7.	39 H	57	1.11 Volts	14.	F8 H	248	4.84 Volts

c. *Hardware Result : Interfacing FPGA to ADC (channel 1 = LM35 Temp. Sensor)*

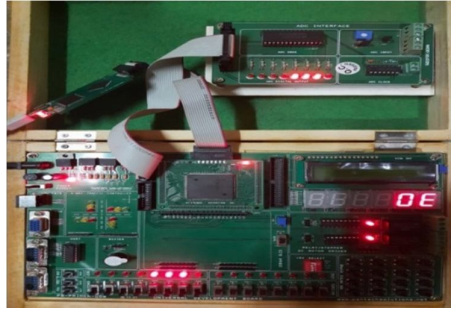


Fig 16: OE H = 27.34 deg C = 81.22 deg F

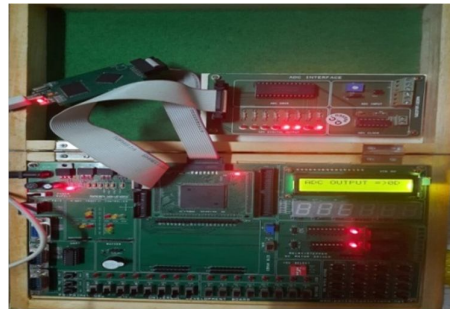


Fig 17: OD H = 25.39 deg C = 74.19 deg F

d. *LM35 TEMPERATURE SENSOR:*



Fig 18: LM 35 [TO-92 package]

e. *Calculation of Temperature from ADC's Digital Output :*

For Example :

Step: 1] ADC Digital O/P = OE H

Step: 2] Convert Bit pattern into Decimal Number :

$$OE = 00001110 = 8+4+2+0 = 14 \text{ (decimal)}$$

Step :3] Convert the Decimal number into its Analog Voltage equivalent :

$$\begin{aligned} \text{Analog I/P Voltage} &= (\text{DEC} / 2^8) * V_{\text{ref}} \\ &= (14/256) * 5 = 0.2734 \text{ Volts} = 273.4 \text{ mVolts} \end{aligned}$$

Step :4] LM35 produces 10mVolts for each deg Celsius / Centigrade :

$$\text{Deg C} = 273.4 \text{ mVolts} / 10\text{mVolts} = 27.34 \text{ deg C}$$

$$\text{Deg Fahrenheit} = [\text{Deg C} * (9/5)] + 32 = [27.34 * (9/5)] + 32 = 81.22 \text{ deg F}$$

B. *ADC (Analog To Digital Converter) with LCD (Liquid Crystal Display)*

a. *Hardware Result : Interfacing FPGA with ADC & LCD*

Figures 19, 20, 21 & 22 represent the result of interfacing FPGA with ADC and LCD displays. The equivalent voltages are also mentioned besides the hexadecimal value of the digital output when channel 0 [TRIM POT] analog signal is selected in the ADC interface board.

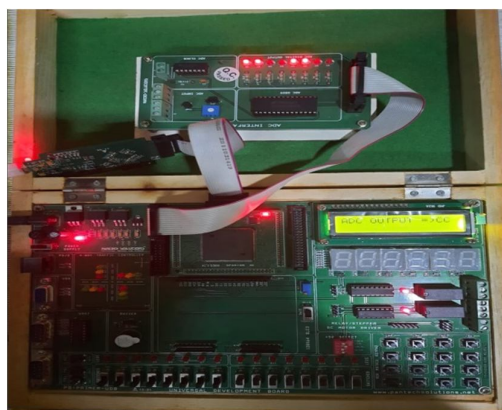


Fig 19 : ADC Output on LCD = CC H = 3.98Volts

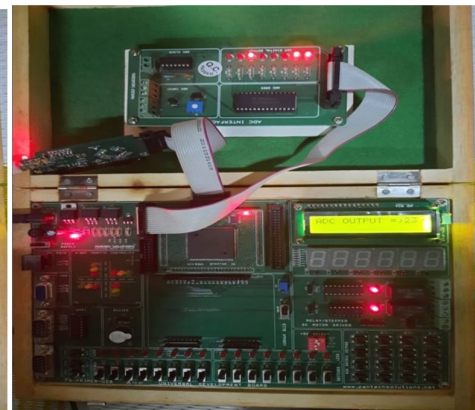


Fig 20 : ADC Output on LCD = 23 H = 0.68Volts

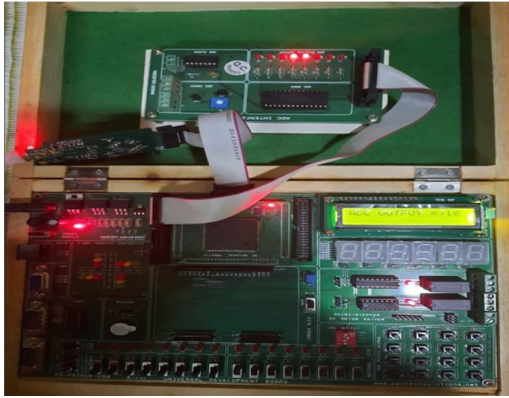


Fig 21: ADC Output on LCD = 18 H = 0.47Volts

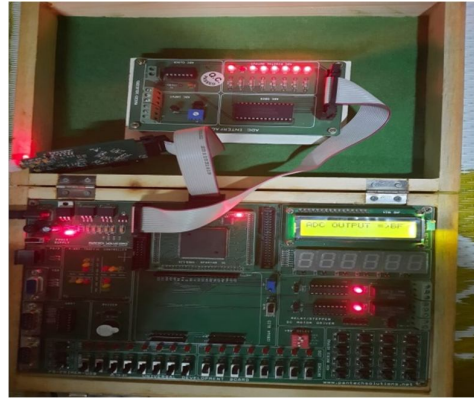


Fig 22: ADC Output on LCD = BF H = 3.73Volts

C. ADC With 7-Segment Display

a. Hardware Result : Interfacing FPGA with ADC & 7-Segment Display

Figures 23, 24, 25 & 26 represent the result of interfacing FPGA with ADC and seven segment displays. The equivalent voltages are also mentioned besides the hexadecimal value of the digital output when channel 0 [TRIM POT] is selected in the ADC interface board.

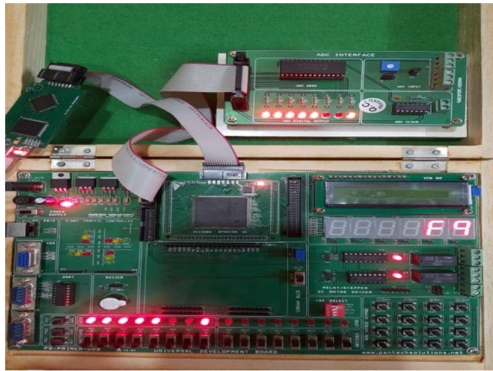


Fig 23: ADC [7-segment Display] = F9 H = 4.86 Volts

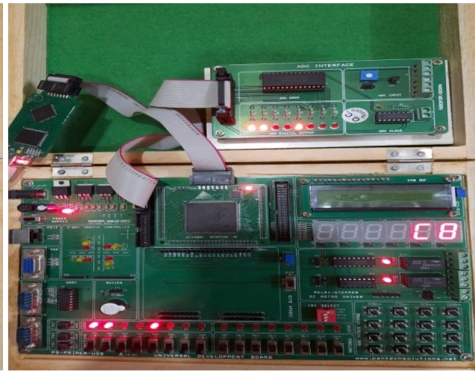


Fig 24: ADC [7-segment Display] = C8 H = 3.91Volts

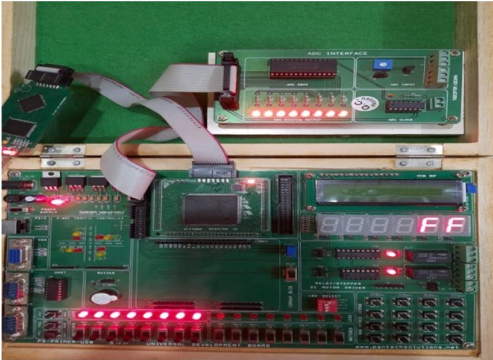


Fig 25: ADC [7-segment Display] = FF H = 4.98Volts

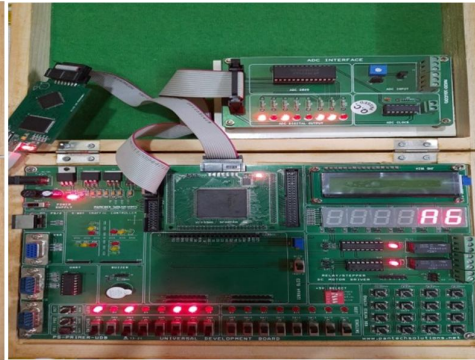


Fig 26: ADC [7-segment Display] = A6 H = 3.24 Volts

IV. CONCLUSIONS

The status of interfacing XILINX FPGA IC Spartan3e XC3S500E-PQG208 with the following ICs:

TABLE II. STATUS OF INTERFACING FPGA WITH ADC, LCD & 7-SEGMENT DISPLAY

IC	EXPERIMENTATION	RESULT
ADC IC 0809CCN	DONE	SUCCESSFUL
LCD IC JHD162A	DONE	SUCCESSFUL
7-SEGMENT DISPLAY IC	DONE	SUCCESSFUL

The challenges encountered while interfacing are as follows:

- i. Generating the clock signal frequency on which ADC works for its conversion from analog to digital form.
- ii. Multiplexing two or more than two 7-segment displays [Persistence of Vision concept]
- iii. Interfacing LCD for Real-time data display.

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