

A Prototype Development of FPGA based Pulse Oximeter for Covid-19

P.K. Gaikwad¹

Assistant Professor, Department of Electronics, Shivaji University, Kolhapur, Maharashtra, India¹

ABSTRACT: The present research work is Field Programmable Gate Array (FPGA) based Soft IP Core implementation as a prototype of Pulse Oximeter for detecting level of SpO₂ percentage to help in diagnosis of Covid-19 patient at prima facie. The research work deploys red wavelength light passing through the finger tip of a suspect patient. The prototype uses photo detector that receives the light from red wavelength to purple and brown colour, according to the amount of saturation level of blood oxygen. If the blood is oxidized the detector receives red wavelength and brown for deoxidized. To detect the intensity of light received and to assert appropriate signal on the output of a reconfigurable device like Xilinx FPGA, we have developed a soft IP Core in VHDL programming language. The Integrated Circuit (IC) based voltage to frequency converter provides the number of clock cycles associated to the status of either oxidized or deoxidized blood.

KEYWORDS: Covid-19, F-V Converter, SpO₂, VHDL, FPGA, Xilinx.

I. INTRODUCTION

The world is going through a pandemic situation of corona virus disease 2019, named as Covid-19. At the stage of prima facie of detecting Covid-19 patient or a related suspect, there are various techniques like thermal scanning etc. However as reported in [1], they evaluated effectiveness of thermal passenger screening for 2019-nCoV infection at airport exit and entry to inform public health decision-making. In that baseline scenario, it has been estimated that 46% (95% confidence interval: 36 to 58) of infected travellers would not be detected, depending on incubation period, sensitivity of exit and entry screening, and proportion of asymptomatic cases. Airport screening is unlikely to detect a sufficient proportion of 2019-nCoV infected travellers to avoid entry of infected travellers. The probable reason behind this appropriate-detection-failure can be distance between thermal scanner sensor and top head skin of the suspect.

Any viral infection attacks the breathing system of a person infected. It is also reported in [2] that, during the ongoing COVID-19 pandemic, a subset of patients are presenting with severe hypoxemia (that is a patient may have below-normal level of oxygen in the blood, specifically in the arteries). While the ease of use and low cost of pulse oximetry makes this an attractive option for identifying problems at an early stage. As mentioned in [3] from home to intensive care units, innovations in pulse oximetry are susceptible to improve the monitoring and management of patients developing acute respiratory failure, and particularly those with the coronavirus disease 2019 (COVID-19). They include self-monitoring of oxygen saturation (SpO₂) from home, continuous wireless SpO₂ monitoring on hospital wards, and the integration of SpO₂ as the input variable for closed-loop oxygen administration systems. To detect hypoxemia based infected or symptomatic patient, it is possible by measuring the oxygen saturation of blood using a pulse oximeter which is a small device that clips to finger tips.

However a healthy person can be judged if its oxygen saturation level is above 90% shown by pulse oximeter device. As mentioned in [7], a normal SpO₂ is usually at least 95%. Some patients with chronic lung disease or sleep apnea can have normal levels around 90%. Medical professionals should be consulted if a patient with suspected or confirmed COVID-19 has SpO₂ ≤ 90%. Supplemental oxygen or other treatments might be needed. If oxygen is available, it should be used for oxygen saturation levels <85%. Levels between 80–90%, and levels that are decreasing over time, often indicate severe disease and the potential for rapid decline.

After treated in hospital or isolation wards, one has to redetect the Covid-19 test by RT-PCR test for discharge procedures. This increases the overall load on the economy of any country. Sometimes if the patient is found non-symptomatic he/she is being discharged after a week or two weeks. But this non-testing discharge may cause serious spread of the infection by discharged patient in this manner. For the balancing purpose of economy as well as non-spread of the infection, the pulse oximeter plays a vital role to detect the blood oxygen saturation level of the patient being discharged. It can be a partial replacement of high-cost RT-PCR test kit; as far as Covid-19 testing of a suspect at

prima facie is concerned. There are various technology based pulse oximeters available in the market [4] which claims that, the Pulse Oximeter can measure and monitor Heart Rate, SpO₂ and Pulse Intensity.

As per the World Health Organization, WHO pulse oximetry training manual [5], it is mentioned that, although pulse oximetry is a simple and reliable technology that can detect low levels of oxygen in the blood, it is only effective if the anaesthesia provider understands how an oximeter works and what to do when hypoxia is detected.

In this research work we have implemented a pulse oximeter which deploys LED-indicators; instead of displaying numerical data or waveforms. Each indicator portrays the range of percentage of oxygen saturation level in the blood. In an urge of detecting the oxygen saturation level in absence or unavailability of a physician, the diagnosis at the early stage may take place. It helps the patient to get alertness of infection when oxygen saturation level is droppings drastically.

The technological platform used in this development is reconfigurable devices from Xilinx Inc, which supports parallel processing for various complicated or simple processes to implement in a concurrent nature. The hardware description languages (HDL) supports parallel processing to overcome drawback of sequential processing available in sequential devices like microcontroller or computerized programming like C, C++ etc. Xilinx ISE tool was used to simulate and synthesize the soft IP Core; developed in Very High Speed Integrated Circuit Hardware Description Language (VHDL).

A pair of red (IR) LED and photo-detector devices was deployed in this prototype development. The IR light sends the light rays passing through finger tip or earlobe of Covid-19 suspect. The photo detector detects the amount of light received after passing through the blood. It generates the associated voltage to be converted in frequency form. Here onward, the role of reconfigurable device functions and asserts the SpO₂ percentage related signals at its output.

II. BLOCK DIAGRAM OF THE SYSTEM

The Figure 1 shows that, the main idea of designing of the pulse oximeter is to sense the intensity of red wavelength light transmitted through the figure-tip; detected at the end of photo detector. If the oxygen saturation level is enough in the blood, the light received by the photo detector would have maximum intensity received. The red colour blood would match the wavelength of the red light hit on the figure-tip and photo detector would generate maximum current through it. Further, this current was converted in to its voltage form by adding voltage divider network. If more is the current passing through photo voltage detector, it signifies that the blood is oxygenated. On the other hand, if the blood oxygen saturation is less in the blood, the maximum red light would not pass through the figure tip; as the blood is either purple or brown. This indicates the deoxygenated blood is there in the body. The SpO₂ percentage might is lower than the expected level of range.

The details of IC- LM331 are given in [6]. This voltage to frequency converter is deployed to provide clock signals to the Field Programmable Gate Array (FPGA). The input of voltage to frequency converter is directly proportion to that of light intensity detected by the photo detector. As if more the current detected by photo detector, then it generates more clock/frequency signals. The Soft IP core developed by VHDL programming language calculates the number of clock signals (that is frequency) available at V-F converter. A process in the soft IP core is designed in such a way that, it calculates number of clock cycles and stores it in a counter form. According to the value of counter, the appropriate signal at FPGA is asserted to indicate the amount of light detected. It predicts that, whether the blood is oxygenated or deoxygenated or is in the between range. The 'Red' signal indicates that the blood is oxygenated and the 'Purple' signal signifies the blood is in between stage of Oxygenated and Deoxygenated. However the 'Brown' signal alerts the patient to be diagnosed seriously as its blood is deoxygenated.

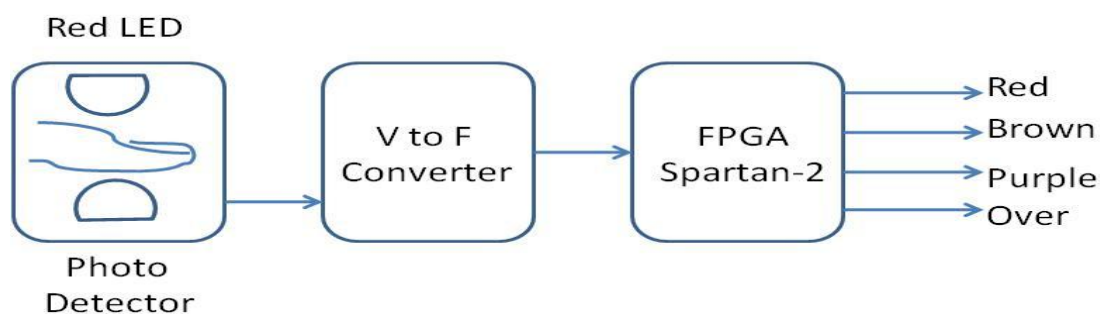


Fig. 1. Block Diagram of the Prototype

III. FLOW DIAGRAM OF SOFT IP CORE

The Figure 2 illustrates the flow diagram for implementation of Pulse Oximetr using VHDL language. As shown in Figure 2, the soft IP core divides the global clock available on-board of the FPGA device. As the V-F clock signals are allowed to enter the FPGA device, it starts counting the pulses and stores in the signal called as ‘count’. There are three stages for comparing the counter values. Firstly, it compares the range of 0 to 7 to activate ‘Brown’ signal. This would further indicate that the patient/suspect is having deoxygenated blood. On the other hand, if it is in the moderate level of percentage of blood oxygen saturation, then a signal named as ‘Purple’ would be asserted high. In the next state, especially when the patient shows enough SpO₂ % then this count would be in the range of 16 to 23. These values are just for the purpose of prototype development, actual values are to be set in the counter-comparison by referring the medical data sheet for comparing the SpO₂ % to show the blood status either oxygenated or deoxygenated. The ‘Over’ labelled signal gets activated when the count goes beyond the value of 23.

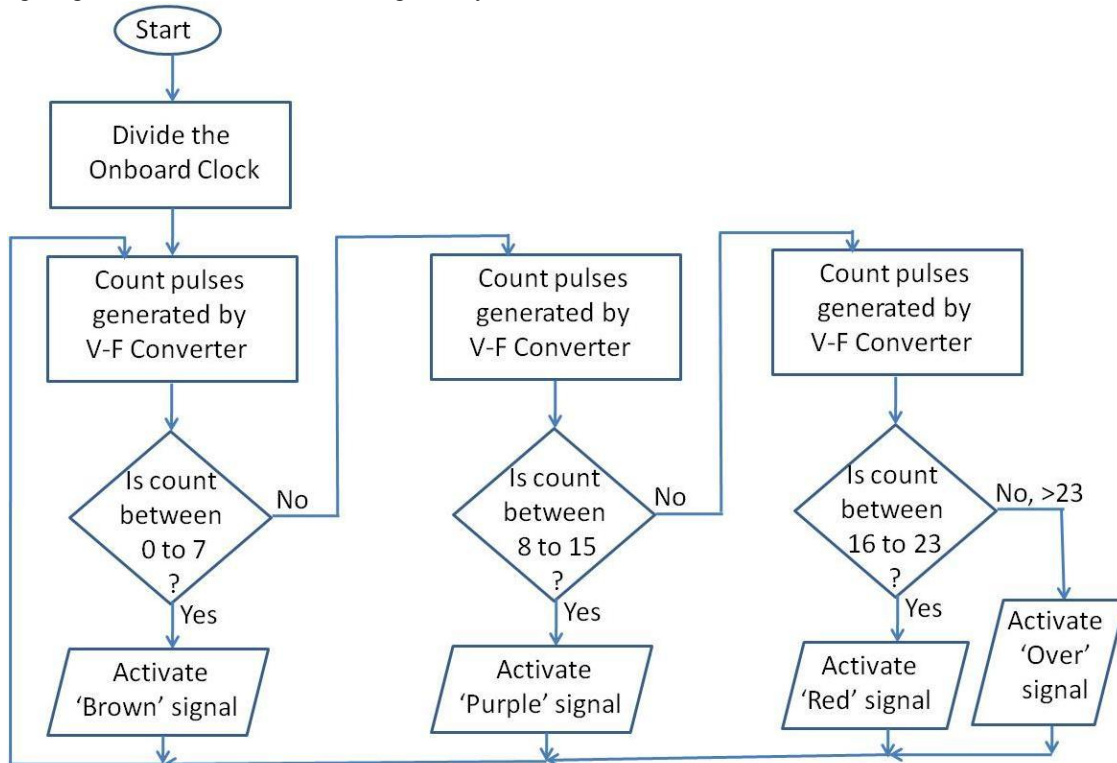


Fig. 2. Flow diagram for Soft IP Core

IV. SIMULATION RESULTS

The Figure 3 shows the simulations results obtained by simulation tool of Xilinx ISE. To understand the simulation results shown in Figure 3 we would divide the discussion in four cases. In first case, the number of oscillations of fin (a signal generated by F to V converter) during clk='0' is 5, so 'Brown' signal is activated to HIGH at +ve edge of 'clk', as it is supposed to activate for 0 to 7 number of oscillations. In second part the number of oscillations of 'fin' during clk='0' is 8, so the 'Purple' signal is asserted HIGH at +ve edge of 'clk', as it is supposed to activate for 8 to 15 number of oscillations. In the case 3, the number of number of fin during clk='0' is 16, so 'Red' signal is activated to HIGH at +ve edge of 'clk', as it is supposed to activate for 16 to 23 number of number. In last that is fourth case, the maximum number of signal, 'fin' during clk='0' is 32, so 'Over' is activated to HIGH at +ve edge of 'clk', as it is supposed to activate for >24 number of number. As soon as the 'counter_value' reaches to the maximum value in the particular case it is assigned a value 'zero' and simultaneously the maximum value is used to assert the particular signal. So the maximum 'counter_value' is not shown in the simulation window.

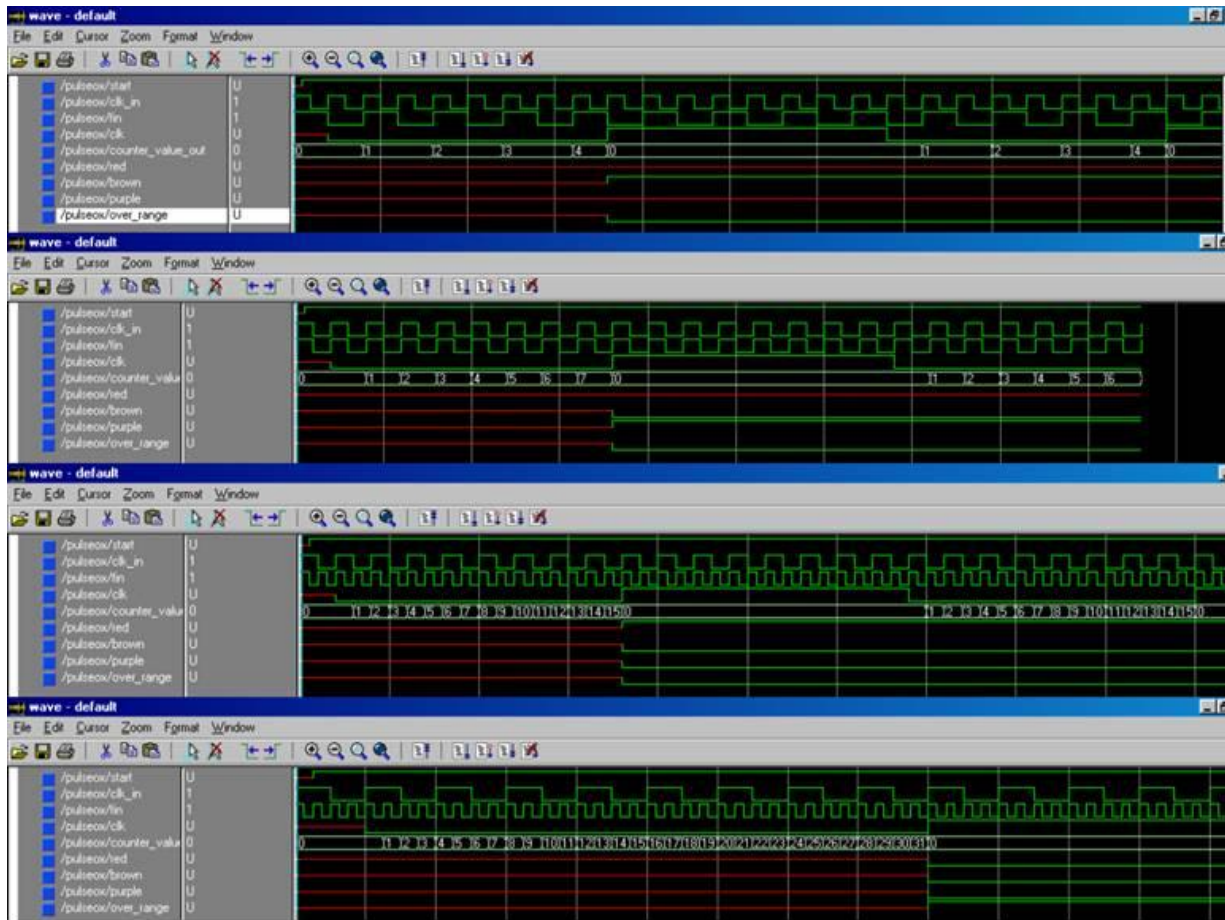


Fig. 3. Simulation results obtained by Xilinx ISE Simulation Tool

V. SYNTHESIS RESULTS OF THE SOFT IP CORE

As a next stage of HDL design flow, the soft IP core has been tested for synthesis process, in which an abstract level program-code, register transfer level (RTL) is transferred into the design implementation in the form of logic gates. The Figure 4 illustrates the synthesis result for the VHDL program developed in this prototype implementation. There are various synthesis results which the Xilinx ISE tool shows after successful process of synthesis. Here we focus on the device utilization for our specific design implementation as shown in Table 1. This prototype development uses Spartan-2 FPGA: 2s150pq208 from Xilinx Inc. It has utilized 20 input/output FPGA device pins from available 140. There are 12 Complex Logic Block slices used for this soft IP Core, where as only 16 D flip-flops or latches have been consumed by this RTL design.

Table 1: Device Utilization for 2s150pq208

Resources	Used	Available	Utilization
IOs	20	140	14.29%
Function Generators	24	3456	0.69%
CLBs Slices	12	1728	0.69%
Dffs or Latches	16	4320	0.37%
Using wire table: xis215-5_avg			

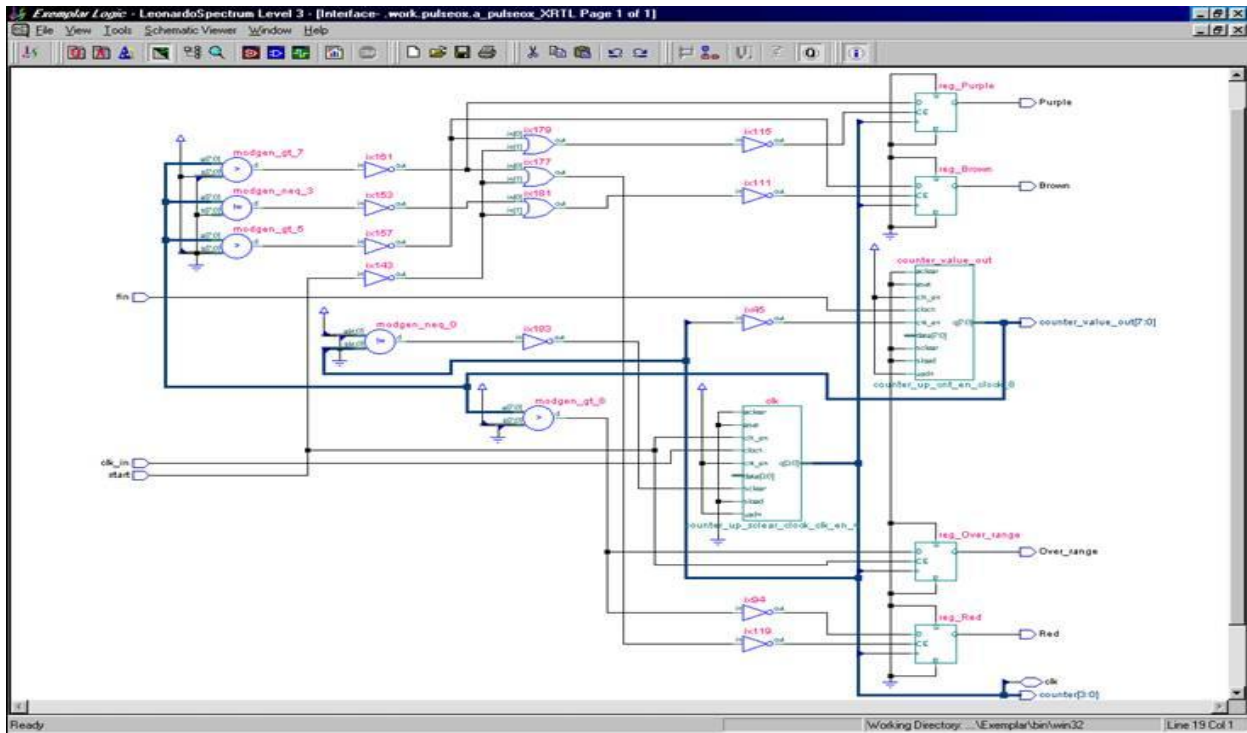


Fig. 2. Synthesis Results of RTL form

VI. CONCLUSION

The research paper presented a prototype development for indicating the range of blood oxygen saturation, so that the range of percentage of SpO₂ would be indicated instead of displaying numerical values that conventional Pulse oximeter shows. To understand the reading one has to be a physician from the concerned field and also it is necessary to be a technical person. To overcome this limitation of existing pulse oximeter, the prototype development here may support both the fields like physicians and technical. In this research work a set of photo transmitter and detector has been deployed to sense the colour of blood of a person under supervision. The output of photo detector is provided as an input for the voltage to frequency converter. The FPGA based system counts the number of clock cycles received and generates necessary signals like, 'red', 'blown' or 'purple' to indicate the range of SpO₂ percentage.

REFERENCES

- [1] Billy J Quilty, Sam Clifford, CMMID nCoV working group , Stefan Flasche and Rosalind M Eggo, Effectiveness of airport screening at detecting travelers infected with novel coronavirus (2019-nCoV), Euro Surveill. 2020 Feb 6; 25(5): 2000080. doi: 10.2807/1560-7917.ES.2020.25.5.2000080. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7014668/>.
- [2] Andrew M Luks , and Erik R. Swenson. Pulse Oximetry for Monitoring Patients with COVID-19 at Home: Potential Pitfalls and Practical Guidance, Annals of the American Thoracic Society, ATS Journals, June 2020. <https://doi.org/10.1513/AnnalsATS.202005-418FR>.
- [3] Michard, F., Shelley, K. & L'Her, E. COVID-19: Pulse oximeters in the spotlight. J Clin Monit Comput (2020). <https://doi.org/10.1007/s10877-020-00550-7>.
- [4] Available from: https://toolz4industry.com/product/fingertip-pulse-oximeter/?gclid=EAIaIqobChMIkLfw08rg6IVxH0rCh0flwgZEAQYBSABEgJbAfd_BwE.
- [5] The WHO pulse oximetry training manual available from: https://www.who.int/patientsafety/safesurgery/pulse_oximetry/who_ps_pulse_oxymetry_training_manual_en.pdf?ua=1
- [6] Available from: https://www.alldatasheet.com/view.jsp?Searchword=Lm331&gclid=EAIaIqobChMI7vaYw5jh6gIVASQrCh0WTAPN EAAAYASAAEgJDp_D_BwE
- [7] Pulse Oximetry and COVID-19, INTERIM GUIDANCE of Department of Health, US. APRIL 27, 2020. Available from: <https://www.health.state.mn.us/diseases/coronavirus/hcp/pulseoximetry.pdf>