

Efficient and Accurate Optical Signal Processing and Digitization System for High Speed Data Acquisition and Analysis

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Abstract. The evolution of optical fiber technology has expanded its utility beyond communication to encompass measurement. Key components include the light source, detection elements, and processing circuits. This paper describes a system for optical signal processing and digitization of light pulses, employing advanced components to enhance data acquisition and analysis performance. The optical signal processing phase employed the LF356N operational amplifier, offering attributes like low bias current, high bandwidth, and rapid settling time. Configured as a transimpedance amplifier, the opamp transformed light signals into corresponding analog voltage signals. Subsequently, the voltage signal underwent digitization using the AD976AN, a 16-bit ADC with advanced features such as high-speed data acquisition and an integrated clock. This ADC was controlled by a Teesny 3.6 board with a fast CPU clock speed of up to 256 MHz, greatly facilitating rapid data analysis and algorithm execution. The hardware circuit underwent meticulous design, simulation, and fabrication, followed by rigorous testing involving various distinct light sources with differing parameters. The digitized and computed parameter values (obtained after subjecting the ADC outputs to the suggested algorithm) exhibited a high degree of similarity in comparison to the observed values on the oscilloscope.

1 Introduction

A vital advancement in the realm of global communication technology was the development of optical fiber technology. During 1970s, the introduction of optical fibers, possessing minimal signal loss had facilitated the transmission of data over long distances at elevated speeds. Subsequent to these breakthroughs, the output quantity has consistently increased, and optical fiber technology is extensively deployed worldwide by the year 2000 [1].

The advancement of optical fiber technology has facilitated the creation of optical processing tools exclusively in fiber, which has minimized insertion losses and enhanced processing accuracy. Fiber optic cables also offer high-performance sensing solutions. The fiber sensors can utilize one or multiple optical parameters of the guided light, such as polarization, wavelength, intensity, and phase [2].

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This makes the optical fiber a versatile tool that can serve a dual purpose: Measure different parameters by monitoring the properties of light that travel through the fiber and act as a communication channel [2].

Currently, these sensors are extensively employed to oversee variable changes in a diverse array of environmental variables such as location, oscillation, tension, force, dampness, heat, substances, electrical flow, consistency, and numerous other ecological aspects. They are also being employed in numerous industries, including aviation, space exploration, infrastructure, and life sciences or ecological surveillance [3],[4],[5],[6].

The light source, light detection and processing circuits play a vital role in optical fibre technology. This paper describes light detection and its processing system in two phases. In phase one, the light detection employing a photodetector and its analog processing using an operational amplifier(op-amp) having features like large gain bandwidth, accelerated slew rate and extremely fast settling time is reported. The second phase describes the digital processing of the obtained analog signal using an analog-to-digital converter(ADC) AD976AN and Teesny 3.6 board Fig.1.

A 16-bit ADC, AD976AN, was integrated, as it provides a voltage conversion range of +10V to -10V, aligning seamlessly with the requirements. Furthermore, this ADC offers a relatively swift conversion rate and comes with customizable on-chip clock and architectural attributes that grants control over the conversion process.

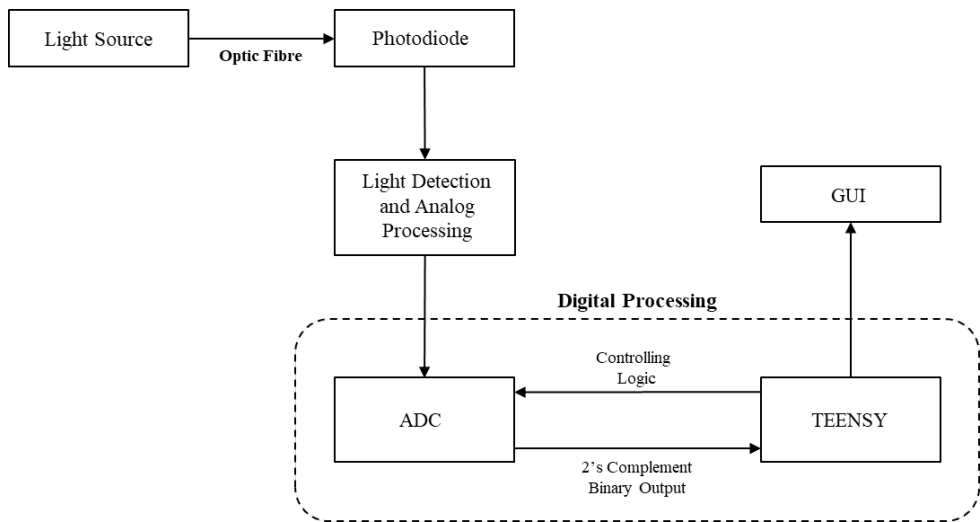


Figure 1: Block Diagram

2 Phase I

2.1 Light Detection and Processing System

The light source emits pulsating light with a power of 10 milliwatts (visual fault locator was employed for testing purpose). This light is transmitted through the optical fiber and focused on the photo-diode. The photo-diode employed was PD638C to detect the light pulses travelling from the source to the diode via the optical fiber. To translate the optical fiber’s light signal into an electric signal, the photo-diode was configured in photo-conductive mode. In

this mode, the light signal is converted to current. The trans-impedance amplifier(TIA) circuit then takes this current output and transforms it into voltage. The use of a TIA circuit instead of a conventional resistor voltage circuit for conversion aids in reducing the noise.

The TIA circuit was implemented using state-of-the-art op-amp, LF356N which offers low bias current, high bandwidth, fast slew rate and fast settling time, simple design, low offset voltage apart from other useful features. This makes it ideal for detecting even small light currents from the photo diode. Furthermore, the op-amp can handle high-frequency variations, thus, making it a suitable choice for integration into the system.

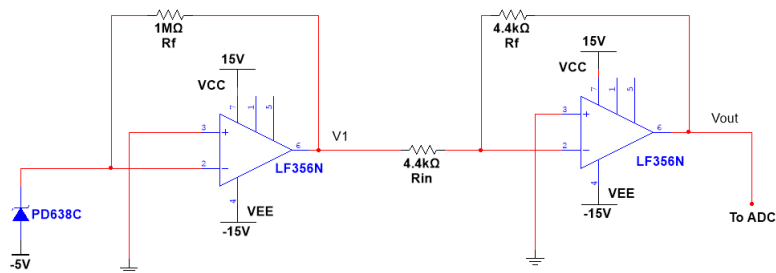


Figure 2: Circuit diagram of the light processing system

To achieve a high gain output from the operational amplifier, a feedback resistor with a value of 1 MΩ was connected between the output and input pins of the TIA circuit. Since the TIA is a simple inverting circuit implemented in an op-amp the voltage output surmounts to:

$$V_1 = I_{in} * R_f \tag{1}$$

After the TIA conversion, the output voltage varies between -4V to -10 V for the minimum and maximum of the output pulse. An inverting amplifier was designed for further signal processing of this negative voltage using the identical LF356N op-amp Fig.2. In this design, the feed-in resistor value was the same as the feedback resistor in the inverting circuit. The output is thus:

$$V_{out} = (-R_f/R_{in}) * V_1 \tag{2}$$

As a result, the minimum and maximum values of the resulting pulse are 4 and 10 V, respectively.

3 Phase II

3.1 Digital Processing

The digitization of the analog output voltage obtained from the phase one is achieved in phase two. Digitization is important for further analyzing and processing the signal using digital signal processing techniques.

Digitization was implemented using ADC AD976AN which communicates with the Teesny 3.6 board for the proper conversion Fig.3. The Teesny 3.6 board provides a CPU clock speed of up to 256 MHz in an overclocked mode, which is ample for accurate calibration during the incorporation of regulated conversions in the ADC. This clock speed is also sufficient for processing the output values used in the calculation of project parameters.

To initiate the digitization process, the ADC utilizes Vin pin to receive the pulsed analog output. The ADC AD976AN is equipped with three controlling pins, namely BYTE, R/C (Read/Convert), and CS pins (Chip select), which were managed by the Teesny 3.6 to implement monitored conversion in the ADC. In addition to these pins, the BUSY pin was used, which typically remains at a LOW state during the conversion process and goes to a HIGH state otherwise, to ensure the completion of the conversion. The conversion time of ADC AD976AN is 4-8 micro-seconds which was sufficient enough to sample an incoming pulse as the output of the signal conditioning process has a pulse width of greater than 1 milli-seconds.

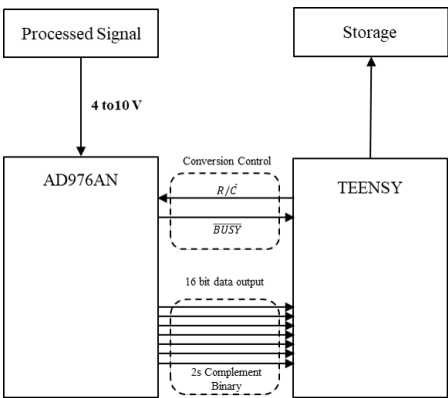


Figure 3: Block Diagram of Digital Processing

Tensy 3.6, manipulates and controls the ADC’s controlling pins. The board initiates sample conversion and scans the BUSY pin to determine when to start scanning for outputs. Once the ADC completes the conversion, its sixteen digital pins are ready to be read, which the Teesny 3.6 does when the ADC’s BUSY pin goes high. The output pins were read from the code from MSB to LSB and stored in a variable, which was then processed to produce the corresponding decimal output. A converter was developed within the code to convert the 2’s Binary Complement output received from the ADC to corresponding decimal outputs.

3.2 Parameter Calculation

Certain parameters of the obtained digital output pulse need to be monitored and calculated such as rise time and pulse width. These two parameters provide information about the accuracy of the conversion, the rise time informs about the acquisition and conversion speed whereas the pulse width informs about the accuracy of the conversion. The values obtained from ADC are subjected to a series of instructions that involve comparing them to predefined values. This process helped in accurately determining the rise time and pulse width of the signals.

The system used two state variables, s1 and s2, to store the most recent and previous outputs of the ADC. By comparing the values of s1 and s2, the system could determine whether the signal was at a rising or falling edge. This helped to accurately identify the state of the signal being processed.

$$if\ s1 < s2\ implies\ Falling\ Edge$$

(3)

Table 1: Description of variables used in Flow Chart

Symbol	Description
s1	current ADC output
s2	previous ADC output
rt_v1	The lower limit for rise time calculation = 0.1 * Vmax
rt_v2	The upper limit for rise time calculation = 0.9 * Vmax
RT	Rise Time
pw	Pulse Width
pw_1	Initiate Pulse Width calculation timer
T0.1	Lower Limit Time for Rise Time
T0.9	Upper Limit Time for Rise Time
T_current	The current time of process in microseconds.

if s2 < s1 implies Rising Edge (4)

It was observed that due to the state of the system not being an ideal one the above-given conditions didn’t occur only at the edges of the pulse but also in different parts of the pulse as well. Due to this, some other constants were also included to determine where the calculation of rise time and pulse width should begin. These constants included:

$rt_v1 = 0.1 * Vmax.....$ (10% of Amplitude) (5)

$rt_v2 = 0.9 * Vmax.....$ (90% of Amplitude) (6)

For the calculation of pulse width, a trigger variable c was used. This variable made sure that the calculation of pulse width was done only when the rise time calculation was over. The variable to initiate the start time, pw_1 (variable used to calculate pulse width), was declared along with T_0.1 (time when pulse voltage reaches 10% of maximum voltage) at the rt_v1 at the rising edge. Once c was triggered to 1 and the pulse reached its falling edge, the ADC output crosses below rt_v1 and the pulse width was calculated by subtracting pw_1 from the current time, which is stored in T_0.9. Both rise time and pulse width calculated were in microseconds. The algorithm implemented for the same is as shown in Fig.4.

3.3 GUI and Storage

The processed data, including the 16-bit digital values and few calculated parameters, were transmitted to the computer via USB serial port communication from the Teesny 3.6. This enables the computer to interpret the output data directly from the processor and display it in a comprehensible format. A graphical user interface (GUI) was created using Python libraries to present the constantly changing ADC values and parameter changes over time. The Matplotlib Python Library was employed to implement a real-time monitoring system for the converted digital output of the input light pulses.

Data received from the processor is also stored in a database with the help of Pandas Library of Python. This data records the voltage output of the ADC, rise time, pulse width as well as other parameters of the pulse including Maximum Voltage, Minimum Voltage, Peak-to-Peak and Frequency of Pulse. All of these parameters are easily calculable either using inbuilt Python functions on the received ADC output values or, calculating them with the help of calculated parameters such as rise time and pulse width.

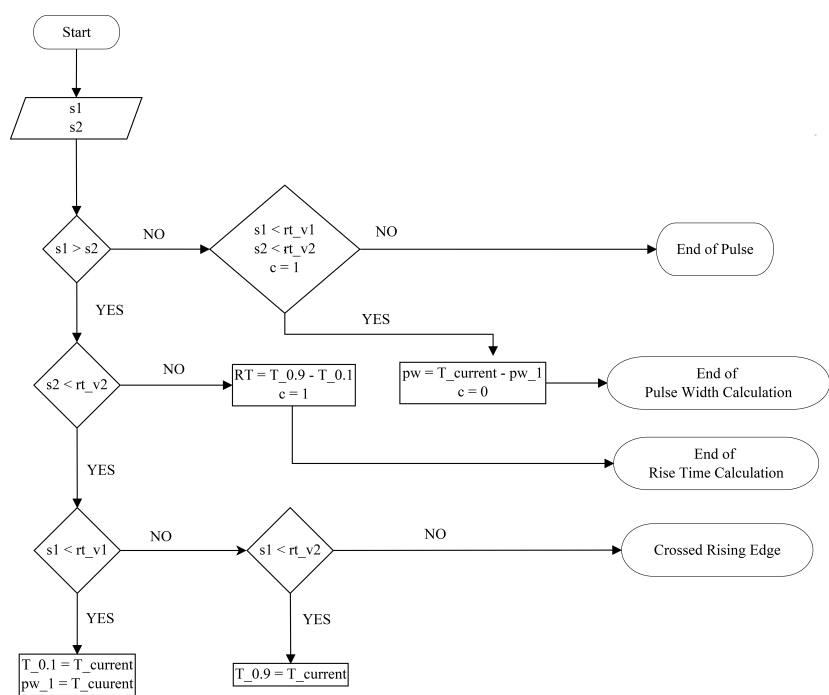


Figure 4: Flow chart for rise-time and Pulse Width calculation

4 Results and Setup

4.1 Setup

To showcase the efficiency of the proposed system, we devised a configuration that contrasted the output characteristics of an analog circuit (visible through a digital oscilloscope (DSO)) with the digitally computed output parameters (derived from the aforementioned algorithms). The PCB for the same was designed and fabricated as shown in Fig.5a and Fig.5b. The complete setup of the light detection and processing system is as shown in Fig.6.

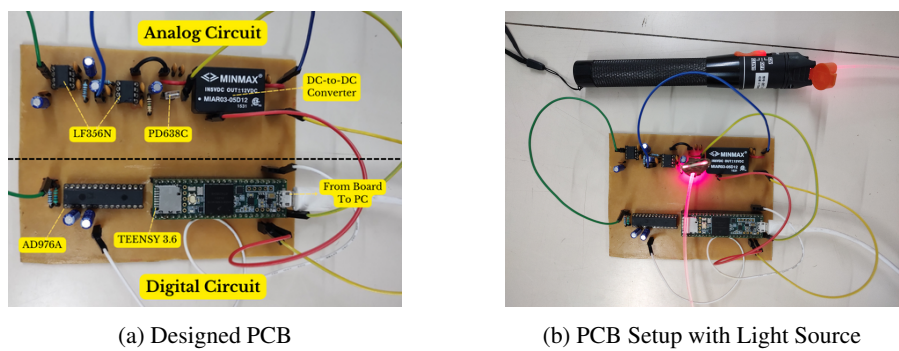


Figure 5: Constructed Circuit for the Proposed Model

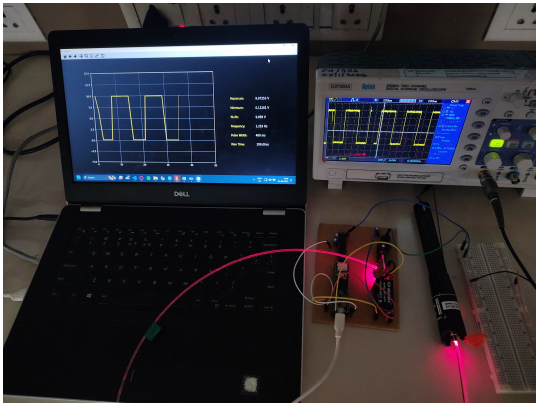
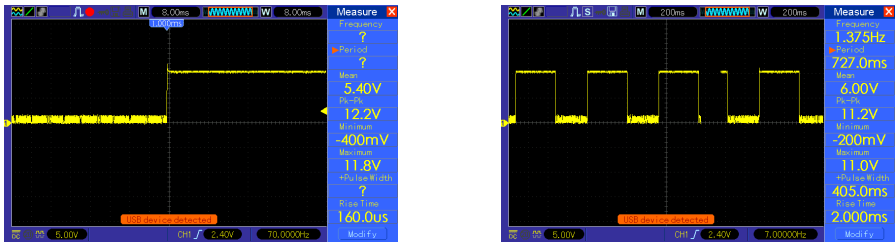


Figure 6: Complete Setup with Optic Fiber and visible outputs on GUI and Oscilloscope

4.2 Results

In the initial setup, we utilized a Visual Fault Detector light source characterized by unchanging intensity, frequency, and amplitude. Subsequently, the readings obtained from the oscilloscope were compared with the computed outputs to discern any discernible variances.



(a) Rise Time as seen on DSO (b) Pulse Width as seen on DSO

Figure 7: Observed value for Visual Fault Detector Light Source

Additional testing on the system employing a custom-designed light source[7] was conducted. This light source was carefully manipulated to change the on-time (pulse width) before being directed onto the setup. We then proceeded to analyze and draw a comparison between the observed results on the oscilloscope and the calculated results from our algorithms, which were found to be consistent and satisfactory.

From the results shown in Table 2, it's clear that the rise time calculated from the digital outputs matches precisely with what is visually observed on the oscilloscope. This indicates a strong alignment between the results obtained through digital analysis and those directly observed through the analog visualization. In simpler terms, the time it takes for the signal to rise from low to high, as determined digitally, is consistent with what we see on the oscilloscope screen. This congruence underscores the reliability and accuracy of the proposed system.

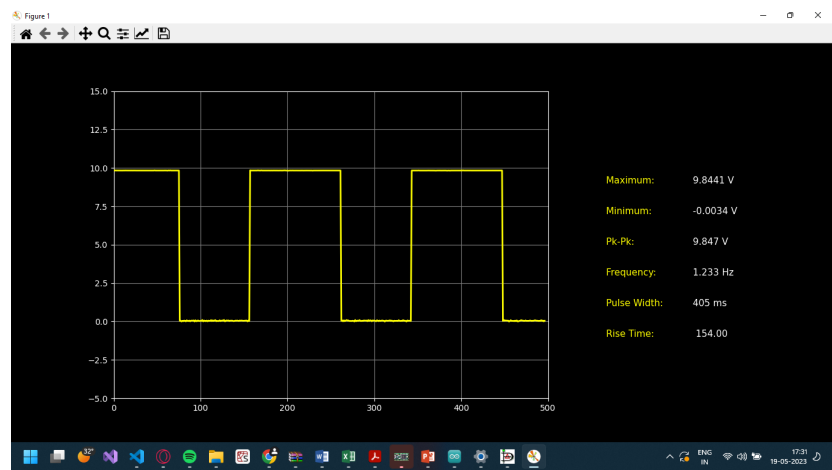


Figure 8: Calculated values for Visual Fault Detector light source seen on GUI

Table 2: Comparison results for observed and calculated values

INPUT	Observed				Calculated			
(ms)	v_max	v_min	pw (ms)	rt (ms)	v_max	v_min	pw (ms)	rt (ms)
10	10	-0.002	10	0.96	9.943	-0.01	9.6	0.96
20	10	-0.002	20	1	9.943	-0.01	19	1.024
30	10	-0.002	30	1	9.943	-0.01	29	0.96
40	10	-0.002	40	0.86	9.943	-0.01	39.649	0.896
50	10	-0.002	50	1.122	9.943	-0.01	49.331	1.024
60	10	-0.002	60	0.793	9.943	-0.01	59.778	0.8
70	10	-0.002	70	0.992	9.943	-0.01	69.3339	1.024
80	10	-0.002	80	0.934	9.943	-0.01	79.428	0.96
90	10	-0.002	90	0.988	9.943	-0.01	89.405	1.088
100	10	-0.002	100	0.96	9.943	-0.01	99.459	0.992
110	10	-0.002	110	1.054	9.943	-0.01	109.385	1.088
120	10	-0.002	120	1.048	9.943	-0.01	119.289	1.088
130	10	-0.002	130	0.878	9.943	-0.01	129.574	0.896

5 Conclusion

This project successfully implements its goal to capture, monitor and digitize light pulses being transmitted through an optical fiber. The high-speed photo-diode used to receive the said light pulses make sure that the loss in data is minimized as much as possible. With the help of reliable operational amplifiers offering features such as extremely fast settling time and fast slew rate the loss in data is minimized further. Capacitors included across the circuit help in reducing the amount of noise to almost zero. This feat is also achieved by having an internal power supply wherein the micro-controller powers the ADC, photo-diode, converters, and thus op-amp as well.

The use of a high-speed ADC helps in sampling almost every instance of the pulse after it has been through signal conditioning. The use of high-speed micro-controllers results in

efficient and accurate calculations of features such as rise time, pulse width, and frequency, wherein the error is just in few microseconds. This will help the user to instantly monitor any change in the light pulse being passed through the optic fiber and take appropriate actions as and when needed.

A user-friendly animation screen helps the user gain satisfaction which brings clarity for them to focus on monitoring their objectives, and with customisable GUI built using the language of Python the user can modify the screen to their own liking at will.

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