Polarization Monitor for High-speed State of Polarization Changes Detection

Petr Dejdar, Pavel Hanak, Petr Munster, and Tomas Horvath

Abstract—The paper describes design of a high-speed polarization monitor system. Describe of hardware design including implementation of FPGA bitstream to the acquisition card and also is presented the graphical user interface (GUI) for processing the measured data. The system is based on Lightwaves2000 Prime controller and a MyRIO device is used for data acquisition. The system is capable sending data from four photodiodes to graphical user interface using the TCP protocol with a sampling frequency of up to 6.5 kS/s. The GUI enables graphical representation of Stokes parameters and also can setup the device parameters. System enables detection of events to an optical fiber caused by changes in ambient conditions using state of polarization (SOP) changes analysis.

Keywords—polarization, SOP, sensing, vibration.

I. Introduction

Nowadays, there is a growing interest in temperature, strain or vibrations measurement using standard telecommunication optical fiber. Vibration detection is the most often used for securing infrastructures, such as railways, building perimeters, or bridges [1], [2]. There are several different techniques for vibrations detection such as fiber optic interferometers [3], Rayleight based reflectometers, or polarization monitors [4], [5].

State of polarization (SOP) analysis for vibrations detection is a simple, cost effective and easily implementable solution. For high speed SOP analysis it is necessary to store and process signals from 4 photodiodes of a polarization monitor. Choosing an appropriate device with a sufficient number of analog input channels for analog to digital (AD) conversion with a high sample rate is crucial.

II. Development of the monitoring unit

A. Polarization monitor

The Lightwaves2000 Prime module [6] for measuring the SOP was used (see Figure 1). The module integrates vertical and horizontal optical prisms and 4 PIN photodiodes for detection of polarization states. Polarization angle of an incoming light can then be calculated from the 4 received electrical signals. Before the signals can be digitized and analyzed, the currents from the photodiodes must be converted to voltage and amplified.

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Firstly, it was considered to use specialized integrated logarithmic amplifiers with current inputs, which would ensure a wide dynamic range. However, with chosen types (ADL5310, AD8304) required parameters can not be achieved. Especially, accuracy of 1% was unsuitable. Critical part is concurrence of 4 channels because each amplifier has a slightly different intercept point and slope of logarithmic transfer curve. Both parameters are temperature dependent, the beginning of the curve even with positive and negative values compared to the nominal catalog data. This would require to do an advanced current and temperature calibration of each channel (amplifier) separately. Therefore, simple transimpedance amplifiers (TIA) [7] with operational amplifiers for which the accuracy of the transfer is given only by the accuracy of the resistors were used. Extending of the dynamic range is then ensured by switching of resistors using a relay, while all 4 channels are switched at the same time.
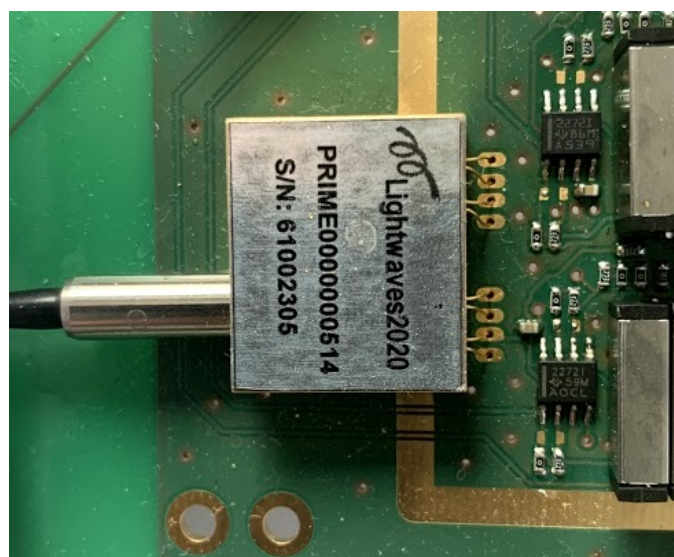

Fig. 1. Module Lightwaves2000 Prime.

B. Data acquisition platform

The output voltages from the TIA are sampled and transferred to a personal computer (PC). Several low-cost USB acquisition platforms were evaluated. StemLab Red Pitaya oscilloscope platform was considered as promising solution, however, by measurements we found out that its low-speed inputs did not have sufficient linearity [8]. In addition, the card overheated during operation, which was undesirable for

an appropriate long term operation of the polarimeter. Another available platforms (LabJack UE9 [9], MCCDAQ 1608G [10]) showed similar shortcomings. The National Instruments platform MyRIO 1950 [11] was chosen as the most suitable solution (see Figure 2). The platform is directly designed for similar embedded applications and has good support for many programming languages.
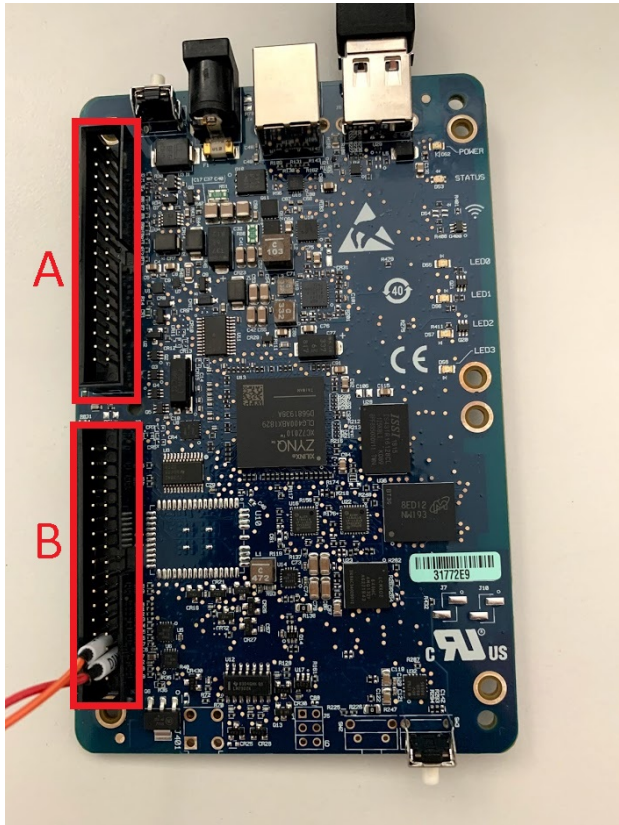

Fig. 2.   National Instruments MyRIO 1950 board.

The block diagram of the polarization system is shown in Figure 3. MyRIO board has two identical connector socket (marked as A and B) and each of them has 4 analog inputs, 2 analog outputs, 16 universal digital I/O, and another specialized pins [11]. Analog input connectors (AI0 – AI3) were used for measuring four voltage levels from the polarimeter and two digital outputs (DIO0 and DIO1) were used to switch the TIAs range. Each MyRIO connector also has +3.3 and +5 V pins, which can be used as a power source for another components. In our case +5 V was used for TIA and also for conversion to –5 V using DC/DC converter that TIA also requires.

C. Gain control

Figure 3 shows the overall scheme of the polarization system. Anodes of PIN photo diodes in the Lightwaves2000 Prime module (IC2) are connected to a voltage of –5 V, so they are polarized in the reverse direction. The photocurrent from their cathodes is connected to four identical TIAs with operational amplifiers IC1 and IC2. Because the photocurrent is negative and TIA uses inverted circuits of Operation Amplifier (OA), there is a positive voltage at their output.

Used TLC2272 OA were selected due to their low noise and ability of the output to operate in the full range of the supply voltage (rail to rail output). For OA feedbacks 3 way exist. There are three pairs of resistors in each way and that can be switched by relays. This can be used to change the gain and thus the suitable dynamic range of the polarization system. For example, for the first channel the basic gain (27 V/μA) is given by the resistor R5 and the parallel connection R1 or R3 can reduce the gain. The resistors were calculated to amplify the measured signal in ratios of 1:5 and 1:10. With simultaneous connection of R1 and R3 it is possible to achieve a ratio of 1:0.91. Resistors R2, R4, and R6 have $0\,\Omega$ in the current version and have been prepared for case when it is necessary to precise control the gain. Capacitor C1 can be used to compensate for the parasitic capacitance of PIN photo diodes, but it is so low and its using is not necessary. TIA outputs are connected directly to the analog inputs of the acquisition platform (IC5A).
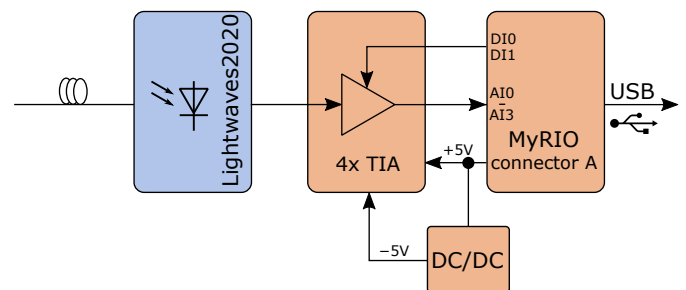

Fig. 3.   Block diagram of the polarization monitor unit.

D. Design of PCB (Printed Circuit Board)

Relays 9092 05 11 from Coto Technology with a 5 V coil switching the signal amplification. Relays have two switching contacts and were chosen mainly because of their shield, which limits the possibility of signal leakage interference. The relays are not switched directly from digital outputs of MyRIO but via transistors Q1 and Q2. For production of negative voltage a switching inverter Traco Power TVN3-0911 was used because it also has a case which protects again electro-magnetic interference. Filter coils L1–L4 are connected to the supply lines. MyRIO platform has separate analog and digital ground to reduce further interference. The relays are connected to digital ground the rest of components to analog ground. The printed circuit board (PCB) has external dimensions of 100163 mm so that it can be mounted in a metal Hammond 1455L1601 instrument box. The board also serves at the same time as a carrier for MyRIO 1950 platform. On its bottom side are 34pin socket strips. Both boards are assembled together with 6 pieces of spacer with M3 threads. The other components of the polarization system are mounted on the top of PCB board. Sensitive analog circuits are as far away from digital circuits as possible. Around the TIAs and relays is some space prepared for case mounting.

Analog inputs on the B connector of MyRIO platform, as can be seen from the diagram in Figure 4, are also used
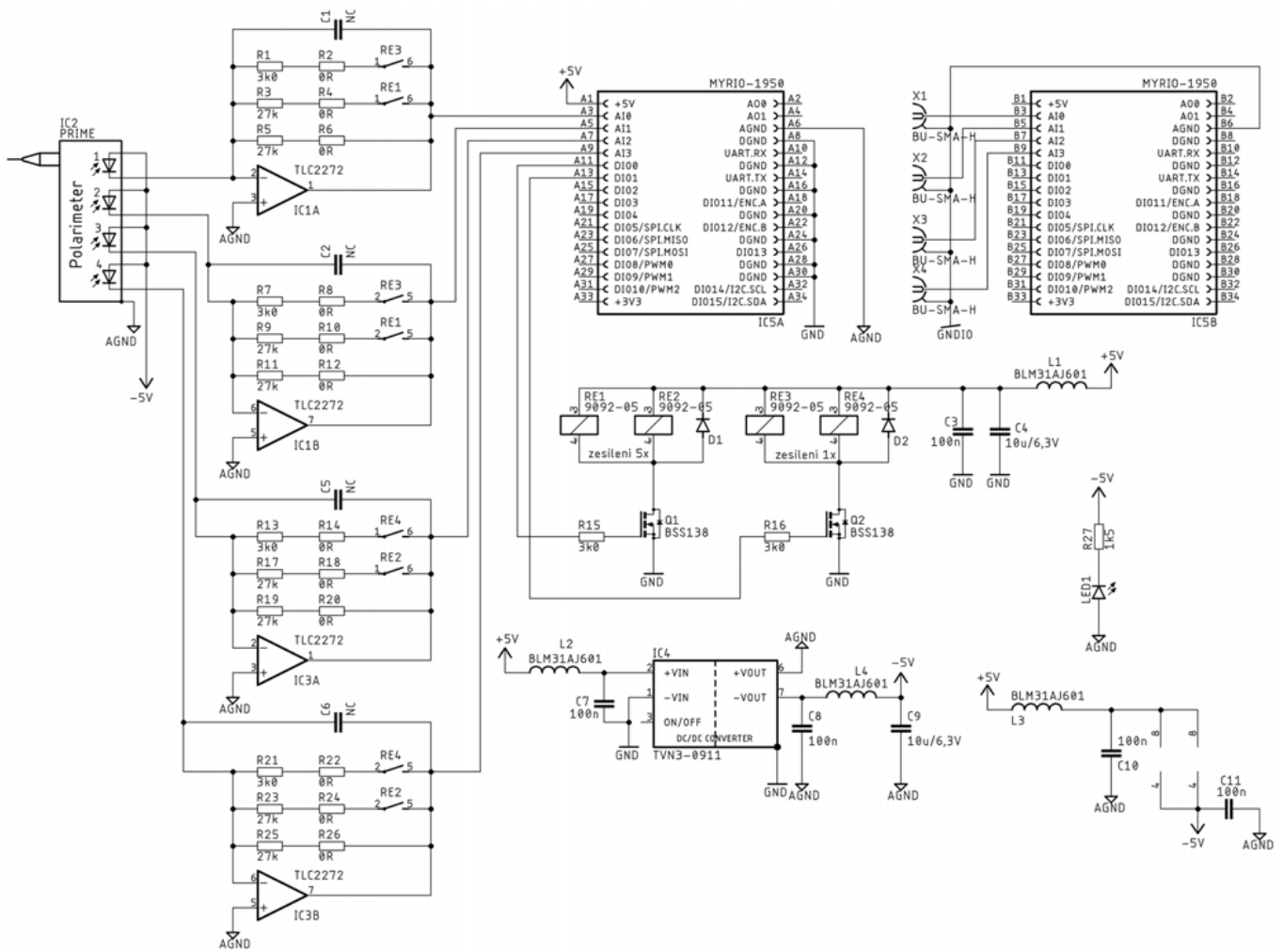
Fig. 4. Overall circuit diagram of the polarization system.

in the the polarization system. These are connected to four SMA connectors on front panel of the device and serve as auxiliary inputs for synchronization of measurements, etc. MyRIO platform access connectors, ie, USB, Ethernet, and coaxial power connector on the back panel. The power input is also used to power the whole polarization system.

III. Software for MyRIO and operating PC

A. MyRIO software

The polarization system software was designed to continuously acquire and send data from four channels at a maximum possible sampling rate. Gain control is performed by changing the logic levels on digital output pins 11 and 13. To store the data it is necessary connect MyRIO via USB to operating PC. MyRIO appears as a client with its IP address and the host PC serves as default gateway because operating PC emulates the network. This setting is the same whether the devices communicate with each other via WiFi (MyRIO 1900) or whether are connected by a USB cable, as in our case [12].

The maximum sample rate of MyRIO if one channel used is $500\,\text{kS/s}$. Data from 4 channels in this application is sended using TCP protocol and the maximum sample rate is $6.5\,\text{kS/s}$.

For real testing, the maximum speed was reduced to $5\,\text{kS/s}$ due to system stability. The program part of gain control is located in an infinite loop between the initialization of the TCP server on port 6486, opening of communication with MyRIO and between reading data from MyRIO and sending them via TCP protocol to operating PC. Thus providing the ability to change the gain value in real-time. Each change takes tens of microseconds [12].

After first tests of basic functions the program was further modified to improve its performance. The first modification of the software is adding the ability to communicate with a remote server. An Axagon USB network card was added to the device which makes possible to use Ethernet interface to connect the device directly to the Internet. The static IP address of the test server is stored in the MyRIO file system and is reloaded after each system startup. The address can be easily changed using SSH and overwriting the file with IP address. It is necessary to restart the device via SSH after overwriting. If the restart does not occur, the device continues to use the old IP address. Data is also sent only if the buffer is full, which is better for the network, and it is also possible to increase the sampling rate in the future work.

B. Software for operating PC

To acquire data it is necessary to start software using LabVIEW for recording data and adjust MyRIO settings on the operating PC. The program can create files in binary TDMS format and store measured data in files. The user can set the time of acquisition or the size of individual files. It is therefore possible to store data in several files for one measurement and thus enable data processing before the set acquisition time has elapsed. It is also possible to change the gain using the Amplification server variable. The Amplification variable in the utility software is the same as in myRIO. Because it is a server variable, it is not created in either program, as is customary with .vi programs but it is created in the project as a separate variable standing above both programs. For end user, it is translated from a local variable, where the user can enter the gain value directly in multiples of the gain, and this value is then recalculated into the server variable.

C. Evaluation on a real telecommunication network

To verify the functionality of the system the detection unit was connected to a single-mode optical fiber link with a distance of 10 km. As an optical source the unit was additionally equipped with a distributed feedback (DFB) laser diode as can be seen in Figure 5. Subsequently, it was necessary to test hardware of the detection unit in real operation. Based on information from the infrastructure owner, optical cables were buried in the non-freezing depth between two railway stations. Since the source signal was implemented into detection unit it was necessary to make a loop between stations. The detection unit was there for several months and the remote control was used to access the operating PC and control measurements. Measurement range length was from tens of seconds to several days [4]. The result of measurement on a real infrastructure can be seen in Figure 7, where signal of moving train is shown. Output of all 4 channels is shown for 90 seconds long record. In Figure 7 we can see a small deviation of the signal amplitude on all 4 photodiodes.
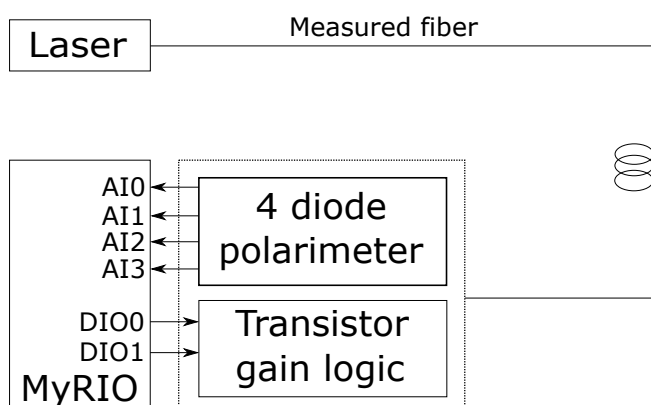
Fig. 5. Scheme of evaluation measurement.

Based on the measurements, it is evident that according to the characteristic deviation of the amplitude, it is possible to recognize the single train from the idle state (see Figure 6).

It is also possible to determine in which direction the train is moving and what type of train it is. This characteristic deviations can be further used for postprocessing of the signal and thus for a deeper understanding of the signal and events causing changes in the state of polarization in optical fibers.
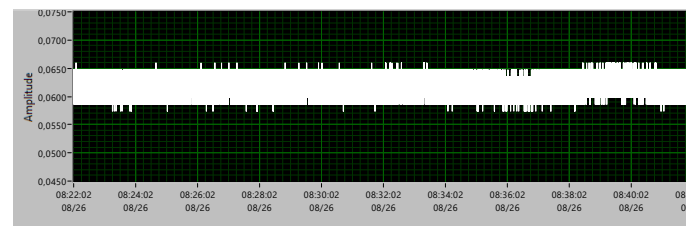
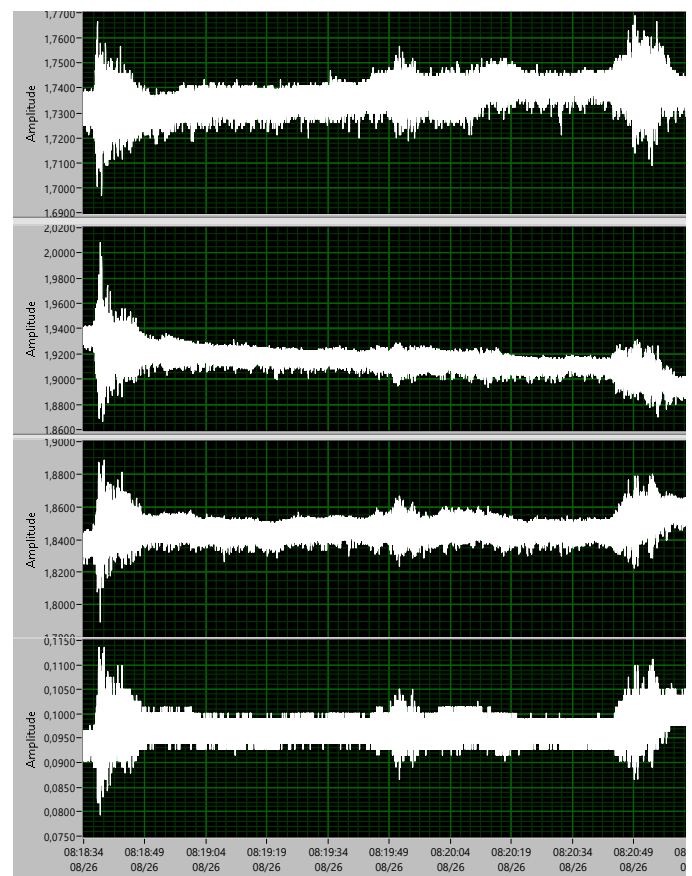Fig. 6. Data from 1 photodiode of polarization unit corresponding to the idle state.

Fig. 7. Data from 4 photodiodes of polarization unit corresponding to the passage of one train.

IV. Conclusion

The polarization monitor unit was designed and developed including a data acquisition board for sending data using the TCP protocol. Furthermore, the logic combining amplifiers and transistors for the possibility of gain control was designed and software for the operating PC was created. The software is able to set the hardware gain of MyRIO, length of data record, and size of individual files. In real-time, it is possible to set the gain using transistor logic using two digital output pins of

MyRIO. Depending on the level of the digital output pins, the polarization monitor signal can be amplified 10×, 5×, 1×, or 0.9×. The system was evaluated in a long time measurement in standard condition and surveys of various lengths have been saved. The system is stable even with surveys longer than 24 hours. The data from the polarization system reliably indicate the presence of a moving train in the measured section. From the data, it is also possible to distinguish in which direction the train is going and what type of train it is. Thus, both the reliability of the system and the possibility of measuring vibrations by detecting changes in the state of polarization were proved.

Acknowledgment

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