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Optoelectronic rotary connector for data transmission

TADEUSZ DROZD, MARCIN JAKUBASZEK,
MAREK ZYGMUNT, ROMAN NIEDZIELSKI[1]

Military University of Technology, Institute of Optoelectronics,
2 Gen. S. Kaliskiego Str., 00-908 Warsaw, Poland, tadeusz.drozd@wat.edu.pl
[1] Designers Sp. z o.o., 27 F. Szuberta Str., 02-408 Warsaw, Poland

Abstract. Many technical solutions require the transmission of data between rotating parts. The article presents a data transmission solution based on an optoelectronic rotary connector. The optoelectronic connector is characterised by high speed of data transmission and long life of the mechanical components, with the choice of synchronous and asynchronous data transmission modes.
Keywords: optoelectronic rotary connector, optical data transmission, detection of optical radiation
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1. Background

A grant was established at the Laser Teledetection Group for the construction of a laser scanner featuring long range, high distance measurement accuracy and high angular resolution. Additional requirements were high data refresh rate and measurement of echo signal strength. In order to meet these requirements, a scanning platform rotating at 3,000 rpm had to be built, with data transmission ensured at a speed of 8 Mbps between the moving part and the base. In analysing the rotating connector market, it was difficult to find a component characterised by high data transfer rates with long life, small dimensions, rotational speed above 3,000 rpm and high concentricity tolerance. A low price was an additional requirement. The closest to these requirements were fibre optic connectors, which are characterised by high data transmission speeds. However they require precise axial alignment of the fibres, which imposes additional requirements on the mechanical design of the scanner. The situation is even more complex if the connector has to operate in full duplex mode. This requires it to operate on at least two wavelengths. This requires an expansion of the optical and electronic systems and increases the costs of connector implementation. For these reasons, the decision was taken to design a purpose-built connector for the laser scanner.

2. The concept of the connector

The development of the connector was based on the assumption that the mechanical elements would not be in contact with each other, where the absence of mechanical parts would ensure a long service life for the connector. Another assumption was high tolerance for any lack of concentricity between the moving and fixed parts. These assumptions were fulfilled by the design shown in Figure 1.

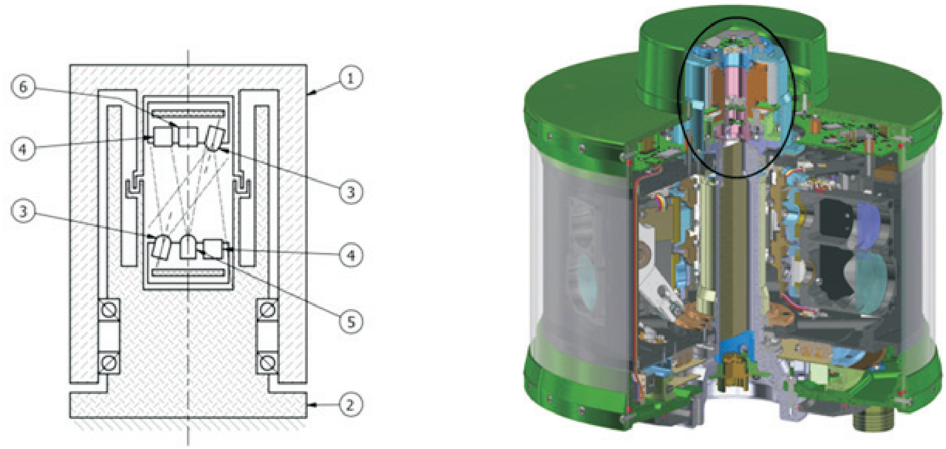

Fig. 1. A view of rotating joint, 1 — moving part, 2 — fixed part, 3 — “850” circuit transmitters, 4 — “850” circuit receivers, 5 — “1550” transmitter, 6 — “1550” receiver The position of the connector in the scanner area is marked with a circle

The connector can transmit data in synchronous or asynchronous mode. Synchronous mode is characterised by a higher effective transmission rate and can therefore be used to transmit large blocks of data. The connector consists of three circuits: two circuits operating at the 850 nm wavelength and one circuit operating at the 1,550 nm wavelength. The “850” circuits are designed for bidirectional asynchronous transmission. The "1550" circuit is used for clock signal transmission, to allow the "850" circuits to work synchronously. The distance between the transmitters is approximately L = 50 mm and the diameter is d = 16 mm. The difference between the source radiation beams was selected to ensure even illumination for the opposite detection surface, covering the whole diameter of the connector. As those circuits operating on the same wavelength should not interfere with each other, the inside of the connector was blackened. The effectiveness of the blackening can be estimated by adopting a simplified model of radiation propagation inside the connector. The power density on the first detection surface can be determined as:

$$D_P = \frac{4 \cdot P}{\pi \cdot d^2}, \tag{1}$$

with: P — transmitter power,
d — detection surface diameter.

Assuming that the incident radiation is reflected from the first surface with a coefficient of ρ, and using Tales' claim, the power density on the opposite detection surface is:

$$D_{PB} = \frac{\rho \cdot P}{\pi \cdot d^2}. \tag{2}$$

The relationship between the power density on the first detection surface and the power density on the opposite detection surface resulting from the reflection can be determined from the following relationship:

$$K = \frac{D_{PB}}{D_P} = \frac{\rho}{4}. \tag{3}$$

From relationship (3) it follows that for an average blackening level, where the coefficient of reflection is approx. 0.08, the power density on the surface illuminated from the reflection will be 50 times lower than that of the surface illuminated directly. The radiation power has to be selected on the basis of both the limited power consumption of the connector and the design complexity of the receiver circuit. At the same time, it should be kept in mind that higher power of the optical radiation source means higher current flowing through the transmitter and therefore a higher level of electromagnetic interference, while higher sensitivity of the receiver system means lower resistance to electromagnetic interference. Both of these factors are important for the correct operation of the connector due to the strong electromagnetic interference generated by the motor and the power supply systems of the scanner.

3. Connector design

A VSLY3850 LED was used as the "850" circuit transmitter [6]. The diagram of the diode driver is shown in Fig. 2. Current control of the LED with a pair of transistors in a current mirror circuit [2] was used in the controller system, which allows for operation at a maximum frequency of 17 MHz. Fast BFR92A transistors were used to build the controller [9]. The current flowing through the LED is 58 mA, which means that the power of optical radiation emitted in the angle of ±18° amounts to approx. 25 mW.

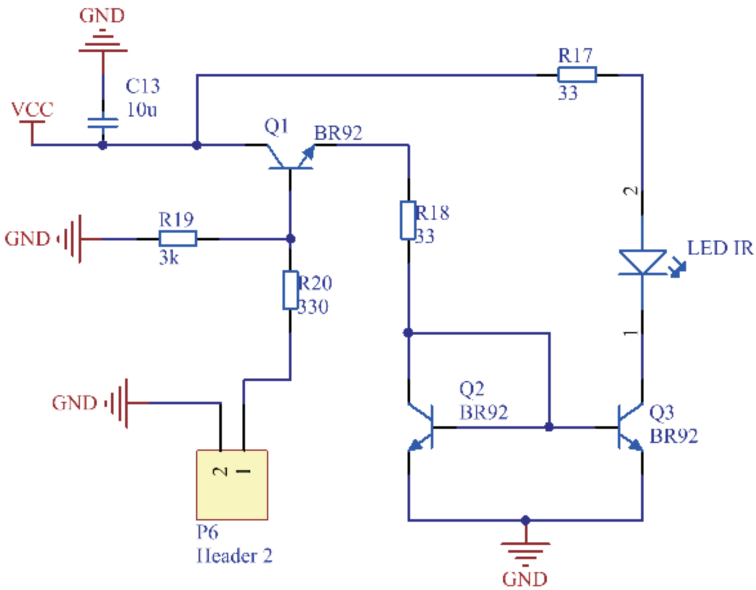

Fig. 2. LED driver

An S5971 photodiode was selected as the detector [3]. The detection area of the photodiode is 1.1 mm^2 and the sensitivity is 0.6 A/W (λ_{850}). Relationship (1) can be used to calculate the power density of the detection area, and then the photocurrent from the following relationship:

$$I_{out} = S_d S_\lambda D_p \text{ [A]}, \tag{4}$$

with: S_d — area of the detector [m^2];
S_λ — photodiode sensitivity for a given wavelength [A/W].

The photodiode was configured as a transimpedance amplifier circuit, as shown in Fig. 3.

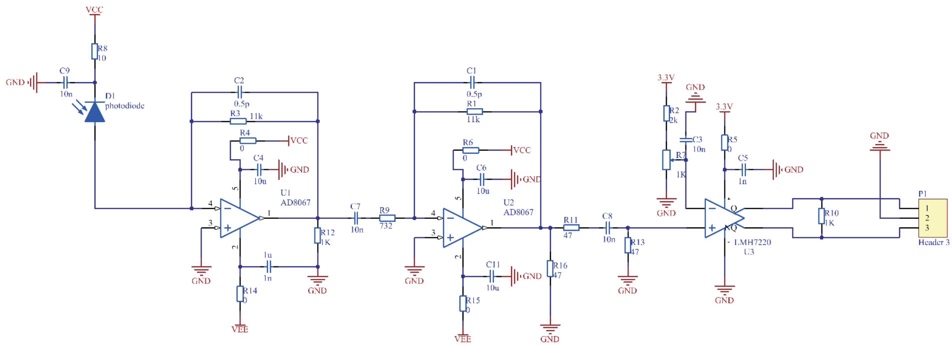

Fig. 3. Design of the receiving circuit

The receiving circuit consists of two amplification stages and a comparator circuit. The strength of the voltage signal after the first stage can be calculated from the following relationship:

$$U_1 = I_{out} R_f \,[\mathrm{V}]. \tag{5}$$

Assuming a 17 MHz band (transmitting circuit band), using the dependencies provided by Analog Devices [4], the value of resistance in feedback (R_f) can be calculated from the following equation:

$$R_f = \frac{GBW}{2\pi f^2 \left(C_{ph} + C_{diff} + C_{in}\right)} [\Omega], \tag{6}$$

with: f — limit frequency resulting from the signal band;
C_{ph} — photodiode capacity;
C_{diff} — capacity between the inputs of the operational amplifier;
C_{in} — operating amplifier input capacity and system ground.

For such conditions the signal voltage at the output of the first stage amplifier is approx. 0.1 V. The voltage signal from the first stage is amplified by a factor of 15, with simultaneous phase reversal. This amplification is sufficient for the operational amplifier [5] to function steadily without the use of external compensating elements. The signal after the second amplification stage is passed to the comparator, where it is compared with the set threshold to determine the received significant state.

For good reception it is necessary to ensure an adequate signal-to-noise ratio. In the presented system, the sources of noise are the photodiode, operational amplifier and the feedback resistor in the transimpedance amplifier.

The signal-to-noise ratio can be estimated from the following relationship [1]:

$$SNR = \frac{I_{out}}{\sqrt{2q\left(I_{out} + I_d\right)B + \frac{4kTBF}{R_f}}}, \tag{7}$$

with: q — electron charge of 1.602×10^{-19} [C];
I_d — dark current of the detector [A];
k — Boltzmann constant -1.380×10^{-23} [J/K];
T — operating temperature [K];
B — band;
F — amplifier noise factor.

The connector housing provides optical insulation from the environment, therefore in relationship (7) there is no noise component originating from the background current. For such assumed conditions the estimated signal-to-noise ratio will be approximately 1,000. The second stage does not significantly change the value of this parameter, as both the noise and the signal are amplified to the same degree, and the noise parameters of the operating amplifiers have values three orders of magnitude lower than the value of the input noise.

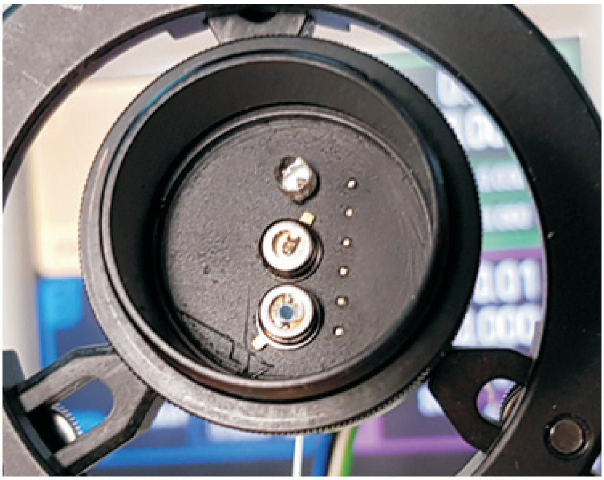

Fig. 4. A view of a single detection surface, from the top: “850” circuit LED, “1550” circuit detector, “850” circuit detector

To reconstruct the signal and adjust it to the standard voltages required for the digital systems, a decision was made to use a comparator. In order to eliminate the interferences that could be induced in the cables carrying the signal from the connector, an integrated circuit was used having a differential output comparator compliant with the LVDS standard. A 1550L LED [7] was used in the construction of the "1550" circuit, with an FGA10 photodiode [8] used as the detector. The electronic solutions used for the "1550" and "850" circuit controller and receiver are identical. A view of a single detection surface is shown in Figure 4.

4. Study

The designed rotary connector has been studied with regard to: influence of the connector rotation on the strength of the transmitted signal, optical crosstalk between the circuits, delay introduced by the connection to the transmitted data and actual modulation rate. The block diagram of the measuring station is shown in Figure 5.

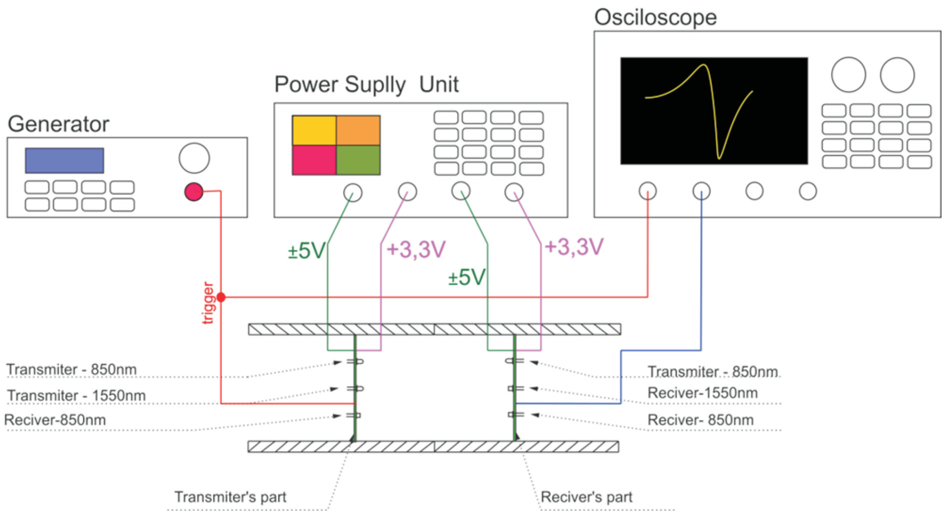

Fig. 5. Block diagram of the measuring station

The influence of the position of the transmitter in relationship to a single circuit receiver as a function of connector rotation is shown in the oscillograms — Figure 6.

a) b)

Fig. 6. Oscillograms from the connector signals in two positions: a) most unfavourable, b) most favourable, yellow — signal triggering the connector's transmitting system, red — signal at the stage II amplifier output, blue — signal at the comparator output, and green — signal at the stage II amplifier output of the opposite detection area

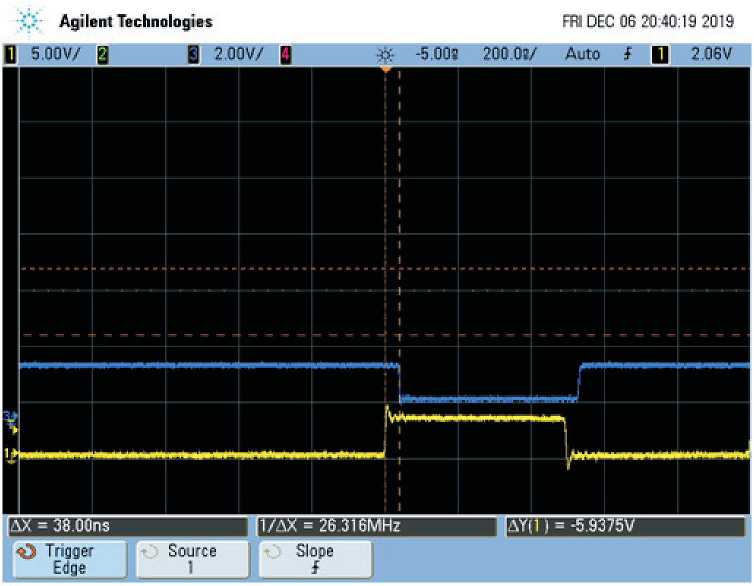

Fig. 7. Delay in connector response to excitation, yellow — signal at the input of the connector's transmitting system, and blue — signal at the output of the comparator

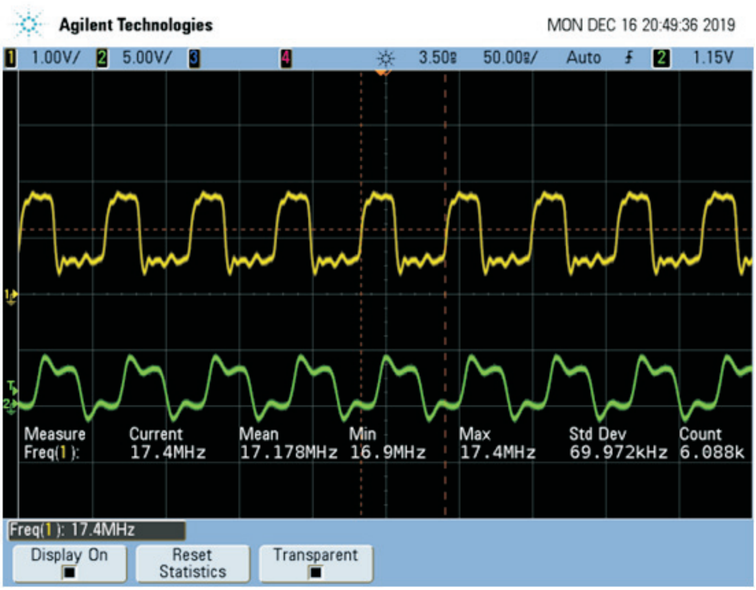

Fig. 8. Oscillogram from the modulation rate measurement, green — signal at the input of the transmitting system, and yellow — signal at the output of the receiving system comparator

The difference in the signal strengths for the two extreme connector positions (red) is as follows: 1.1 V to 1.4 V, which is 0.3 V. This change in the signal does not in any way affect the correctness of determining the significant conditions for the received data. A significant issue in this type of device is crosstalk between channels caused by internal reflections. The design of the connector utilises blackening to limit the occurrence of this phenomenon. According to the calculations, no crosstalk between the circuits was identified, as shown by the green signal in the oscillograms — Figure 7. The level of diffuse radiation is so low that it was not found at the level of 50 mV.

The level of delay of transmitted data is shown in Figure 7. The delay between the sent and the received pulses is 38 ns, and is constant regardless of frequency.

The results of the modulation rate measurements are shown in Figure 8. The oscillogram shows that the assumed modulation frequency band was obtained.

5. Conclusions

The inclusion of commercially available components ensures that the optoelectronic connector system is an excellent alternative to the specialised rotating connectors typically used for data transmission. An unquestionable advantage of this connector is the absence of the mechanical contact elements which significantly reduce the maximum rotational speed and life of such elements. Three optical circuits were used, enabling synchronous and asynchronous transmission. The adopted solution allows high effective data transmission speeds to be achieved, depending solely on the components used. The presented solution has been filed for patent at the Polish Patent Office [10].

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Tadeusz Drozd https://orcid.org/0000-0002-0577-3200
Marcin Jakubaszek https://orcid.org/0000-0001-9157-6627
Marek Zygmunt https://orcid.org/0000-0001-9058-9178

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T. DROZD, M. JAKUBASZEK, M. ZYGMUNT, R. NIEDZIELSKI

Optoelektroniczne złącze obrotowe do transmisji danych

Abstrakt. W wielu rozwiązaniach technicznych istnieje potrzeba transmisji danych pomiędzy będącymi w ruchu obrotowym częściami urządzenia. W artykule przedstawiono rozwiązanie optoelektronicznego złącza obrotowego do transmisji danych. Złącze charakteryzuje się dużą szybkością transmisji danych oraz wysoką żywotnością mechaniczną, pozwala na pracę w trybie synchronicznym i asynchronicznym transmisji danych.

Słowa kluczowe: optoelektroniczne złącze obrotowe, optyczna transmisja danych, detekcja promieniowania optycznego
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