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Optical fiber telemetry link to transmission of measuring signals

Abstract. The theoretical part of this thesis contains the most important definitions concerning telemetry systems. Furthermore, some measurement methods of telemetry link transmission parameters were described. The phenomena accompanying the transmission of signals by optical fiber have been characterized. The classification, characteristics, principle of operation and the construction of elements consisting of the built telemetry optical fiber link were presented. The practical part of the work was to study and analyze the metrological properties of the built telemetry fiber optic link, in which the input signals can be derived from the DHT11 ambient temperature and humidity sensor, or can be TTL signals in the frequency up to 1 kHz.

Streszczenie. W części teoretycznej niniejszej pracy zaprezentowano najważniejsze definicje z zakresu systemów telemetrycznych. Omówiono także wybrane metody pomiaru parametrów transmisyjnych łącza telemetrycznego. Scharakteryzowano zjawiska towarzyszące transmisji sygnałów za pomocą łącza światłowodowego. Przedstawiono klasyfikację, właściwości, zasadę działania i budowę elementów składających się na zbudowane światłowodowe łącze telemetryczne. Praktyczna część pracy polegała na przebadaniu i przeanalizowaniu właściwości metrologicznych zbudowanego światłowodowego łącza telemetrycznego, w którym sygnały wejściowe mogą pochodzić z czujnika temperatury i poziomu wilgotności otoczenia DHT11 bądź mogą być to sygnały TTL w zakresie częstotliwości do 1 kHz. (**Światłowodowe łącze telemetryczne do transmisji sygnałów pomiarowych**)

Keywords: telemetry system, telemetry fiber optic link, ambient temperature and humidity sensor, single mode optical fiber

Słowa kluczowe: system telemetryczny, światłowodowe łącze telemetryczne, czujnik temperatury i wilgotności otoczenia

Introduction

In the modern world, telemetry systems play a very important role in monitoring, in real time, various types of processes that require highly specialized measurement systems and the use of the latest technological advances. Generally speaking, telemetric systems are now becoming a substitute for traditional measurement systems. Telemetry is used, for example, for controlling the work of power equipment, such as: power grids, hot-water pipelines or gas pipelines. It can also be used, among others, in the broadly understood industry, in control and measurement systems, metrological research, as well as in modern intelligent buildings.

The purpose of telemetric systems is to collect (acquire) processing and transmission of information about the monitored process or facility using various available transmission media. Currently, the most commonly used transmission medium is single mode optical fiber.

The use of light for data transmission has fascinated scientists and inventors for a very long time. An example is the experiment conducted in 1854 by John Tyndall, showing the effect of total internal reflection of light in the water pipe and an experiment with photons carried out in 1880. However, the intensive development of optical fiber technology took place only in the second half of the fifties of the twentieth century and continues to this day. It is expected that the further evolution of optoelectronics will be based on the continuous modification of systems using wave multiplexing (xWDM) and the use of new materials for the production of optical fibers.

The advantages of fiber optics are primarily the very high throughput, no emission of external electromagnetic field, high security of data transmission and resistance to various types of external interference.

In this paper, a fiber optic telemetry link was characterized, which was built and tested. Obtained results of the measurements have been analyzed to determine suitability of fiber optic telemetry link in remote measurement and control systems.

Construction, principle of operation and types of telemetric systems and links

Telemetry is a field of telecommunications, dealing with techniques for sending measurement signals at a distance. These signals, in the telemetry system (Fig. 1.), are acquired using various types of sensors. Then they are sent via wired or wireless links to the point of activation and processing of measurement data. At this point, operations on the signal are performed, including: recording of measurement results, calculation of statistical parameters (arithmetic mean, standard deviation) and parameters related to accuracy (uncertainty of measurement), preparation of measurement results (determination of the condition in which it is currently system – high or low state, as well as exceeding a certain value), generation of signals intended for regulation and warning signals, providing data on the instantaneous measured or controlled value.

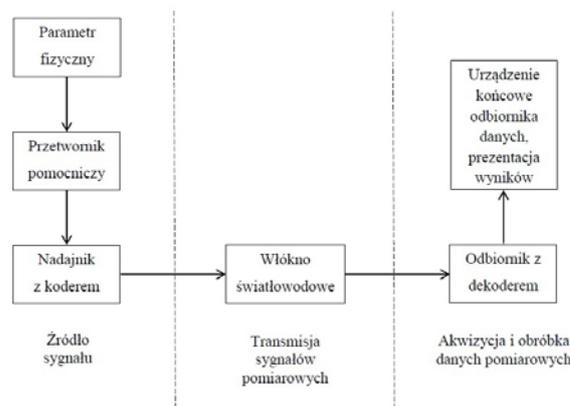


Fig. 1. Diagram of the basic telemetry system with a fiber optic telemetry link [own results]

There are three types of telemetry systems:

- single-channel system – enabling simultaneous measurement of only one value of physical size, and the transmission is carried out in a serial manner,
- multi-channel system – enabling simultaneous measurement of many values of physical sizes, and transmission is carried out in a parallel manner,
- selective system – enabling the simultaneous measurement of several values of physical sizes, and

transmission is carried out in a serial manner using a multiplexed data bus.

In transmitting devices used in optoelectronics, the choice of the optical signal source depends on the transmission range, and hence on the optical value of the output power. This is determined by the sensitivity of the transmitter, which determines, in a decibel measure, the ratio of the power introduced to the transmission medium to the power drawn from the source (power needed for generation). This parameter is marked as C_{TR} . There are three types of transmitters [1,2]:

- infrared diode (IR) for transmission in the I optical window (850 nm), with a sensitivity of -20 dB, dedicated for multi mode optical fibers,
- low power laser (LPL) designed for transmission in II optical window (1310 nm) or III optical window (1550 nm) with a sensitivity of -10 dB, dedicated to single mode optical fiber,
- high power laser (HPL) with a sensitivity of 0 dB for transmission in II optical window (1310 nm) or in III optical window (1550 nm), dedicated to single mode optical fibers.

The functions that the light sources have to fulfill are [3]:

- providing a suitably high energy of radiation with a specific wavelength or wavelength range,
- ensuring the stability of the light radiation intensity during transmission,
- ensuring consistency in time and space, i.e. the coherence of radiation emitted by the source. For reasons of coherence, light sources are divided into: incoherent (thermal and luminescent sources), with little coherence (light emitting diodes) and with high coherence (single-mode lasers).

Photodetectors – light radiation detectors or photo receivers – are mounted in receiving devices of fiber optic telemetry systems. Their task is to receive the optical signal from the link and convert it to an electrical signal, usually of a current nature. You can call them light-to-current converters.

The characteristic parameter of a photoreceptor is its sensitivity. It is expressed in a decibel measure and determines the minimum level of radiation power that can be detected. Classifying receivers based on sensitivity (C_{RE}), their following types are distinguished [1,2]:

- low sensitivity receiver (photodiode) with a sensitivity of -28 dB,
- high sensitivity receiver (phototransistor, Darlington phototransistor), with a sensitivity of -40 dB.

They are used in single mode and multi mode transmission.

In fiber optic telemetry systems, a light source with a photodetector are connected by a single mode or multi mode optical fiber – an optical waveguide. The structure, principle of operation and geometrical, damping and propagating parameters of fiber optics have been described in the papers [4,5,6].

For transmission in the optical system, modulate the light source with a code sequence, this is a prerequisite. For this purpose, light modulators are used, which carry out the process of coding information, the carrier of which is a beam of light [3]. There are two techniques for modulating the optical signal [3,6]:

- internal (direct) – keying the light source (rarely used),
- external (indirect) – using fiber optic modulators (most commonly used).

Direct modulation of the current of light source, both laser and diodes, causes negative phenomena – widening the spectrum and modulating the length of the emitted light wave. This aspect should be taken into account in high-speed systems and systems with wave division multiplexing

(xWDM) [3,6]. For this reason, this solution has a narrow application. The only possible direct laser modulation is the modulation of the frequency achieved by a small modulation of its current (the modulation of the amplitude of radiation is treated as a parasitic modulation). It is caused by the dependence of the frequency generated by the radiation laser on the current intensity [6]. The external modulation of light radiation is based on the fact that the luminous flux, obtained from a laser operating at a constant value of current, is modulated by an external light modulator (Fig. 2).

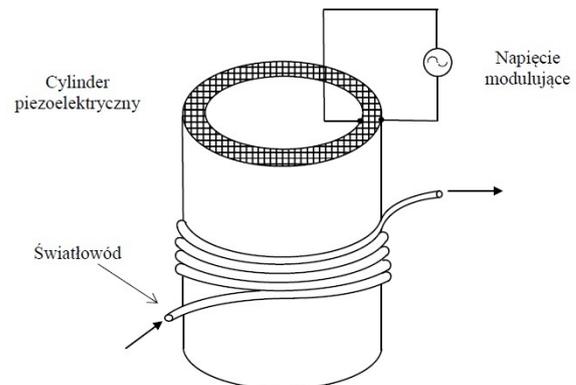


Fig. 2. Fiber optic phase modulator [3]

An example of a commonly used optical fiber modulator is a waveguide phase modulator (Fig. 2.), in which the refractive index changes in the electro-optic material caused by the external electric field were used. Examples that achieve a wide band of modulation (40 GHz and more) are semiconductor waveguide electro-absorbing modulators, acoustooptical modulators and interferometric modulators [6].

Optoelectronics have many types of light modulators. They can be classified according to the manufacturing technique (volumetric, planar and fully fiber), the type of physical phenomenon used (electrooptical, acoustooptical, magneto-optical, absorption, mechanical) and the type of modulated optical parameter of the carrier wave (phase, frequency, amplitude, polarization state) [3]. Optical fiber modulators are widely used due to the possibility of installing them in a fiber optic path without interrupting it. This is advantageous due to the lack of additional attenuation caused by fiber optic connectors [3].

Optical power losses and propagation delay in the telemetry optical fiber and selected methods for their measurement

Optical power losses significantly affect the transmission of the light signal, because they limit the transmission range. The occurrence of damping phenomena has many sources. We can classify them as follows [1]:

- power losses occurring at the optical fiber link:
 - power losses arising in the optical fiber: the results of radiation, i.e. leakage of the signal from the optical fiber path and losses outside the optical fiber structure;
 - power losses generated at the connection point – fiber optic connectors – detector: result from the method of connecting optical fibers (welds, connectors), use of fiber optic couplers, etc. ;
- propagation losses in fiber:
 - material losses: result from the properties of the used materials for the production of optical fibers and the process of their production. Due to various types of defects (material heterogeneity) and impurities (elements of various metals and OH^- ions), resulting from doping of glass, the phenomenon of scattering and absorption of optical power

arises. OH⁻ ions play a special role due to the resonant nature of the interaction and cause the spectral characteristics of the fiber optic transmission to split into three optical (transmission) windows. Another source of absorption may be metal ions: Cu²⁺, Cr³⁺, Fe²⁺ and hydrogen H₂, which has a special effect on the wavelength of 1240 nm [3]. In addition, due to the non-ideal physical properties of the glass, the energy of the guide mode goes to other modes; this causes the radiation of some of the power from the optical fiber. Thus, the smaller the fiber optic impurities - the process of cleaning materials from contaminants is more accurate, the lower the material losses;

- waveguide losses: are caused by losses arising from bending (microbendings and macrobending) and heterogeneities (microcracks) on the border between the core and the cladding. This part of the losses results from the technology of making the fiber structure.

Attenuation is a quantity that quantifies the decrease in electromagnetic power (energy decrease) between fiber optic points for a given wavelength λ [1,7]. They are described by the formula [1,7]:

$$(1) \quad A(\lambda) = 10 \cdot \log \frac{P_1(\lambda)}{P_2(\lambda)} \quad [\text{dB}]$$

where: $P_1(\lambda)$ – optical power at the beginning of the optical fiber [W], $P_2(\lambda)$ – optical power at the end of the optical fiber [W].

Describing optical power loss in optical fiber, in addition to attenuation, we can also use a quantity called unit loss (loss) - attenuation per any length [1,7]. This parameter is described in the following formula [1,7]:

$$(2) \quad \alpha(\lambda) = \frac{A(\lambda)}{L} = \frac{10}{L} \cdot \log \frac{P_1(\lambda)}{P_2(\lambda)} \quad \left[\frac{\text{dB}}{\text{km}} \right]$$

where: L – distance between points 1 and 2 of the optical fiber in which the optical signal power was measured [km].

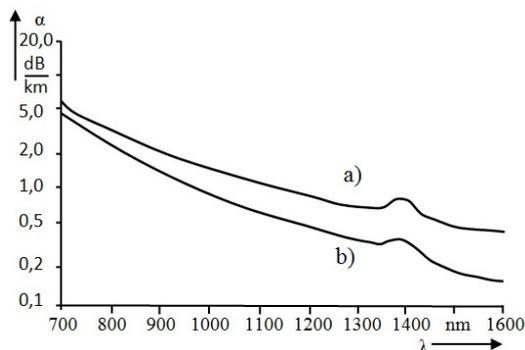


Fig. 3. Diagram of unit attenuation of fiber optics: a) multimode, b) singlemode [1]

From the formula (2) it follows that the unit attenuation of the optical fiber is a function of the wavelength of the light (Fig. 3.). For telecommunications optical fibers, described in the ITU-T recommendation as G.652, G.653, G.655 and G.657, the unit attenuation value is: for the I optical window – 3 dB / km, for the II optical window – 0,4 dB / km, for the III optical window – 0,2 ÷ 0,25 dB / km.

The measurement of attenuation and unit attenuation is most often carried out using a reflectometric or transmission (insertion) method. The reflectometric method is based on Rayleigh scattering (photons are absorbed due to the heterogeneity of glass and immediately radiated without loss, but in random directions) [1,6,8]. The optical reflectometer (OTDR) saves data in the time domain with a return signal. The reflectometric measurement consists in

analyzing the backscatter power. The result of the measurement is presented in the form of a reftype (reflectometric curve), on the basis of which the attenuation and attenuation unit value of a optical fiber can be determined, having access to only one end (Fig. 4.).

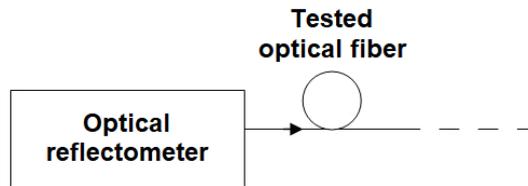


Fig. 4. Diagram of the measurement system for the reflectometric method [7,8]

Transmission method (insertion) consists in placing the tested transmission medium between the transmitter and the light receiver [7,8]. It is necessary to build a reference system consisting of a light source and an optical power meter (Fig. 5.). Then, the tested optical fiber is inserted into the measuring system (Fig. 6.).

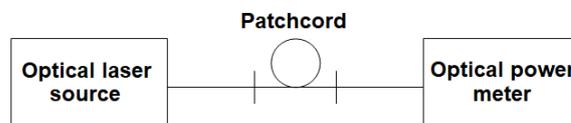


Fig. 5. Scheme of the reference system used in the insertion method [7,8]

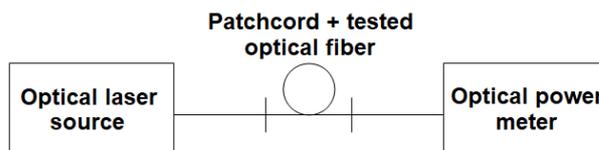


Fig. 6. Scheme of the system for measuring fiber attenuation by inserting [7,8]

The transmitter may be, e.g., a laser or a halogen lamp. It is important to ensure a stable light source during the measurement (stability of wavelength and intensity). The receiver must be synchronized with the frequency of light modulation, it must have a linear characteristic in the entire range, i.e. take over the entire radiation coming out of the optical fiber. An important element of the whole reference system is the patchcord, a short section of the optical fiber with the same nominal characteristics as the tested optical fiber.

Measurement of insertion damping consists in first measuring the P_1 power in the reference system (patchcord), and then inserting the examined optical fiber into the measurement system and re-measuring the optical power P_2 . Then, the attenuation calculation should be made on the basis of formula (3), taking into account the attenuation of the connectors used in the method [7,8]:

$$(3) \quad A(\lambda) = 10 \cdot \log \frac{P_1(\lambda)}{P_2(\lambda)} - A_c \quad [\text{dB}]$$

where: A_c – the average nominal attenuation of the measured optical fiber connection with the measuring system [dB].

By delaying the propagation of a fiber optic telemetry system, it is meant the time needed to pass the light signal between one end of the fiber optic link, which is increased by the time needed to convert the electrical signal to the optical into the transmission system and the optical signal to the electric into the receiving system.

Optical signal transmission is carried out only in the core of the optical fiber. This means that the speed of light

propagation in an optical fiber can be determined from the following formula [1,2]:

$$(4) \quad v = \frac{c}{n_1} \left[\frac{\text{km}}{\text{s}} \right]$$

where: $c \approx 3 \cdot 10^5$ km/s – speed of light in a vacuum, n_1 – refractive index in the core of the optical fiber.

By measuring the propagation delay of a fiber optic telemetry system τ , using the oscilloscope method, you can determine the total delay introduced by the transmitting and receiving system. For this purpose, an input signal is applied to one channel of the digital oscilloscope and the output signal is output to the other channel. The time shift between the pulses corresponds to the propagation delay of the fiber optic telemetry system.

Having the speed of light propagation in the core of optical fiber (4) and the propagation delay of the fiber optic telemetric system τ , you can determine the total delay introduced by the transmitting and receiving system using the formula:

$$(5) \quad \tau_{TR/RE} = \tau - \frac{L}{v} \quad [\text{s}]$$

where: $\tau_{TR/RE}$ – total delay introduced by the transmitting and receiving system of the fiber optic telemetry system [s].

Characteristics of the test stand

The fiber optic telemetry link for the transmission of measurement signals, which was constructed, is the main element of the test bench (Fig. 7.). It consists of a transmitter block and a receiver block. They are connected by single mode optical fiber G.652 with a length of about 1 km (973 m). Measurement signals are acquired from the temperature and humidity sensor DHT11. It is possible to transmit TTL signals in the frequency range up to 1000 Hz and read them using an oscilloscope connected to the receiver.

Depending on the frequency of the transmitted signal, the propagation time of a fiber optic telemetry system can be determined. In addition, the built measuring station gives the opportunity to measure the power level of the optical signal, as well as to calculate the difference in power levels. In connection with the above, this system can be used, among others when measuring temperature and humidity in a climatic chamber, and can also be used during transmission of code sequences with TTL electrical parameters.

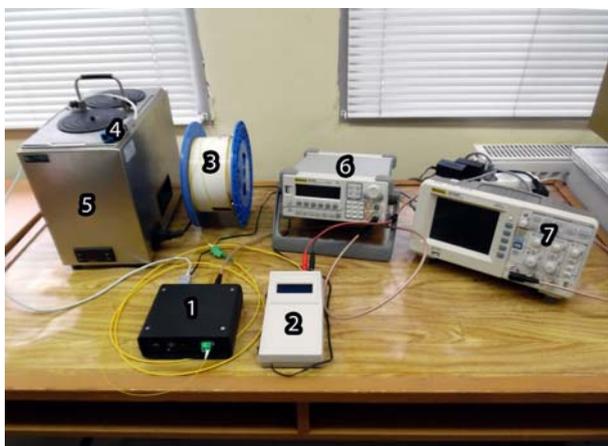


Fig. 7. Test stand: 1 – transmission system, 2 – receiving system, 3 – optical fiber according to ITU-T G.652 973 m long, 4 – temperature and humidity sensor DHT11, 5 – climatic chamber (laboratory bath), 6 – generator RIGOL DG1022, 7 – oscilloscope RIGOL DS1052E [own results]

The built transmission system (Fig. 8, Fig. 9. and Fig. 10.) makes it possible to obtain a signal from a sensor or a generator, its appropriate modulation and sending it to the receiver. The digital input signal can be a signal containing information about the ambient temperature and humidity is obtained from the DHT11 sensor (the sensor is attached to the transmitter block by means of a cable with DB-9 connector) or a code sequence compatible with the TTL standard (BNC socket allows you to enter a signal to the transmitter rectangular TTL 5 V with frequency not exceeding 1000 Hz), which is then fed to the digital input of the microcontroller Atmega 328. The values are converted programmatically to the data stream and go to the SFP insert, which sends information to the optical fiber via a built-in laser. Data is sent using amplitude modulation. This is the easiest method of data transmission. The high frequency of the clock (at least 800 MHz) is imposed by the laser diode with the highpass filter in the SFP module [9]. The carrier wave is filtered using a SAW (Surface Acoustic Wave) filter with an acoustic surface wave to minimize distortion of the measurement signal. The modulation signal is a data stream – a code sequence. The obtained signal after modulation is sent in serial form through the serial port TX on the output. It comes to transmitting at 1200 baud rate, in 1-second intervals (you can change it programatically – then the optical power will change).



Fig. 8. Front panel of the transmitter block [own results]

By means of the switch „Transmisja pomiaru temp. i wilgot./Transmisja sygnału TTL” the user must choose which type of reading he wants to be on the receiver block display. If you are interested in reading telemetry data, and not analyzing the transmitted TTL signal, the switch in question should be set in the „Transmisja pomiaru temp. i wilgot.” (Fig. 8.). When reading the attenuation and optical power of the signal, the position of the switch on the front panel of the transmitter is not it matters.



Fig. 9. Rear panel of the transmitter block [own results]

The task of the receiving system (Fig. 11., Fig. 12.) is to receive the signal from the transmitter, its appropriate demodulation and display on the LCD display or to send the TTL signal to the oscilloscope.

The process of data reception takes place in the following way, the SFP insert receives the transmitted light signal and sends the value of the received power using the I2C bus. The signal that comes out of the fiber optic receiver SFP should be demodulated (carry out the inverse process to modulation) amplitude to obtain the string data again.

A demodulator is a SAW generator with the same frequency as that in a transmitter that works continuously, but when it receives a second signal with the same

frequency, the output results in a conversion product (a low frequency signal that is the same as transmitted). This is a kind of RF mixer. Next, data of the string type is changed (thanks to the "Arduino Nano" board) to UART data, i.e. to unipolar digital signals with a level of + 5V. They reach the microcontroller over the UART bus to the processor's UART inputs. It processes them into temperature and humidity values presented on a 2x16 character LCD screen.

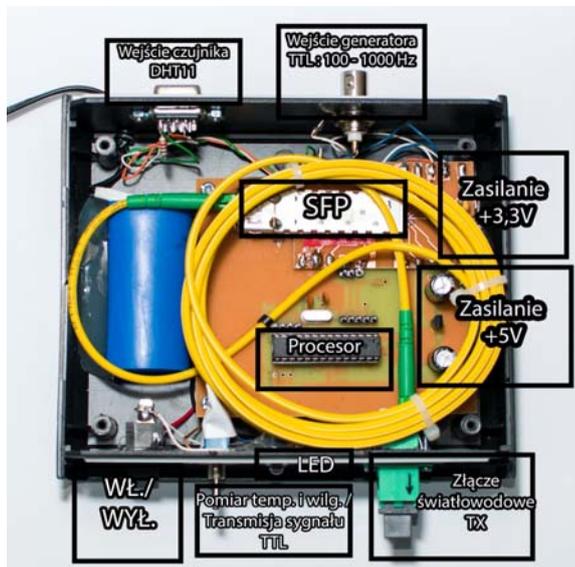


Fig10. The interior of the transmitter block [own results]

The front panel of the receiver block (Fig. 11.) only contains a 2x16 LCD display. On the left side of the device there are two two-position switches. At the bottom there is an „Wł./Wył.” switch that activates the receiver, and above the switch selects the displayed measurement results „Tłumienie/Telemetria”.

At the top of the receiver block (Fig. 11.) there is (from the left): red „Kalibracja” button, outgoing optical fiber – patchcord and radio measuring sockets (+ and -) which are the block output enabling the oscilloscope connection.

In addition to the digital conversion, the signal reaching the SFP on the receiver side is also converted into the RSSI value - determining the signal level expressed in dBm, i.e. the optical power that is on the receiving photodiode. The values of incoming signals expressed in dBm, as well as their difference (depending on the tested optical fiber), ie attenuation expressed in dB, are presented on the LCD display when the "Suppression / Telemetry" button is in the „Tłumienie” position (Fig. 11.). In the case of difference measurement (indicated as LOSS parameter on the display) it is necessary to calibrate the meter with the red „Kalibracja” button (Fig. 11.). This operation is necessary, because the microcontroller memory needs to be written to the cell, the level of the signal sent by the transmitter for the currently connected optical fiber-patchcord, so that it can be based on it as the reference value of the initial value. After pressing the „Kalibracja” button, the processor resets the counters and remembers this value. The description of the attenuation measurement using insertion method was described earlier.

It is also possible to check the telemetry (in this case, read the current temperature and humidity in the environment in which the DHT11 sensor is located), when the „Tłumienie/Telemetria” switch is in the „Telemetria” position. Parameters that can be determined using the built-in measurement set are:

- optical power coming to the receiver [dBm];
- losses in the optical power link (attenuation of telemetry link) [dB];

- temperature [°C];
 - humidity [%];
 - frequency of the TTL signal transmitted over the link [Hz];
- propagation time of the telemetry system and total propagation time of the transmission and receiver system [s].



Fig. 11. Front panel of the receiver block RX and its side and top view [own results]

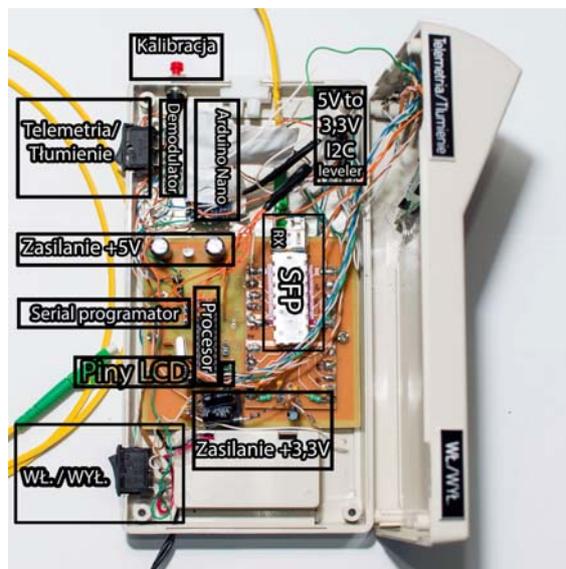


Fig. 12. Receiver block – top view with open cover [own results]

Research results and their analysis

In order to investigate and carry out the analysis of the metrological properties of a fiber optic telemetry link for the transmission of measurement signals, a measurement station was set up (Fig. 13.).

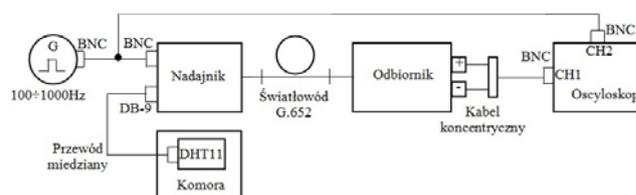


Fig. 13. Diagram of the measurement station [own results]

First, the calibration of the set to measure attenuation of fiber optic telemetry link was carried out. The obtained result is treated as a reference of the initial value. The aim of the measurement was a static analysis of the obtained results in order to check whether the power of the light radiation generated by the laser is stable over time and whether it is possible to take the average value obtained from the measurement results for further calculations of the laser radiation power. The algorithm for carrying out the measurement is as follows:

- connect with each other by means of a patchcord (derived from the receiver) block of the transmitter with the receiver block,
- The temperature and humidity sensor is connected via a connector DB-9 connect with the transmitter block,
- on the transmitter block, set the switch to position „Transmisja pomiaru temp. i wilgotn.”,
- on the receiver block, set the switch to position „Tłumienie”,
- transmitter and receiver connect to the power source and then start using the switches „WŁ./WYŁ.”,
- after starting the station in ten-second intervals, make one hundred calibration measurements of the relative reference level expressed in dBm.

Then, measurements of the relative power level of the received signal were carried out. The aim of the measurement was a statistical analysis of the obtained results to determine in what range the signal strength from the fiber optic telemetry link is included, as well as determining whether the mean value obtained from the measurement results can be taken for further calculations of laser radiation power. The algorithm for carrying out the measurement is as follows:

- without turning off the devices into the tested system, use a fiber optic connector to connect a 973-meter optical fiber according to ITU-T G.652,
- after making the connection, in the same way, in ten-second intervals, one hundred measurements of the relative power level of the received signal expressed in dBm.

On the basis of statistical analysis of the results of the series of measurements of the relative reference power level and the relative power level of the received signal, the measurement uncertainty defined in the study [10] and the confidence interval defined in [11] (Table 1.) were determined. The unit attenuation value of a fiber optic link built from a single-mode telecommunications fiber optic marked as G.652 working in the II optical window.

Table 1. The results of statistical analysis of a series of relative reference power level measurements and the relative power level of the received signal and the unit attenuation of the telecommunications fiber optic cable according to ITU-T G.652 working in the II optical window [own results]

| Parameter | Fiber optic patchcord 2 m long | Optical fiber 973 m long with fiber optic patchcord |
|-----------------------------|---|---|
| Arithmetic mean | 5,39 dBm | 4,84 dBm |
| Standard deviation | 0,02 dBm | 0,08 dBm |
| Standard uncertainty type A | 0,00 dBm | 0,01 dBm |
| Standard uncertainty type B | Range: 10,1 dBm Resolution: 0,1 dBm Accuracy: 0,8% + 5c | |
| | 0,31 dBm | 0,31 dBm |
| Total uncertainty | 0,31 dBm | 0,31 dBm |
| Extended | 0,31 dBm for $t_{\alpha} = 1$ | 0,31 dBm for $t_{\alpha} = 1$ |

| | | |
|-------------------------------------|--|--|
| uncertainty | 0,63 dBm for $t_{\alpha} = 2$ | 0,62 dBm for $t_{\alpha} = 2$ |
| | 0,94 dBm for $t_{\alpha} = 3$ | 0,93 dBm for $t_{\alpha} = 3$ |
| Confidence interval | (5,38 ; 5,39) dBm for $t_{\alpha} = 1$ | (4,83 ; 4,85) dBm for $t_{\alpha} = 1$ |
| | (5,38 ; 5,39) dBm for $t_{\alpha} = 2$ | (4,83 ; 4,86) dBm for $t_{\alpha} = 2$ |
| | (5,38 ; 5,39) dBm for $t_{\alpha} = 3$ | (4,82 ; 4,87) dBm for $t_{\alpha} = 2$ |
| Medium attenuation of optical fiber | Attenuation of a fiber optic connector: 0,13 dB | |
| | $A(\lambda) = 5,39 - 4,84 - 0,13 = 0,41$ [dB] | |
| Unit attenuation of optical fiber | $\alpha(\lambda) = \frac{0,41}{0,973} = 0,42$ $\left[\frac{\text{dB}}{\text{km}} \right]$ | |

The next step was to study the transmission of TTL signals with different frequencies and a comparative analysis of the source signal with the received waveform. The aim of the measurement was to determine the time of optical fiber propagation and propagation time of the whole set depending on the frequency of the transmitted signal. On this basis, after deducting the fiber optic propagation time, it will be possible to determine the propagation time of optoelectronic modules. The algorithm for carrying out the measurement is as follows:

- connect the laboratory generator output with the transmitter and directly with one of the oscilloscope channels using T-connector,
- on the transmitter block, set the switch to position „Transmisja sygnału TTL”,
- start the generator – the waveform must comply with the TTL standard, i.e. the amplitude can not be greater than 5 V,
- frequency of the waveform should be set to 100 Hz,
- calibrate the indications of both channels on the oscilloscope,
- record two oscillograms of the studied waveforms – the first one so that at least one period can be seen, and the second one to read the rise time of the transmitted waveform through the telemetry link,
- increase the 100 Hz waveform frequency (tune the generator up to 1000 Hz).

Table 2. The propagation time of single mode telecommunications fiber, the propagation times of a fiber optic telemetry system and the total delay introduced by the transmitting and receiving system of a fiber optic telemetry system [own results]

| The propagation time of optical fiber | The refractive index in the core of optical fiber: 1,4515 | |
|---------------------------------------|--|---|
| | $\tau_p = \frac{0,973 \cdot 1,4515}{3 \cdot 10^8} = 4,7$ [μs] | |
| TTL signal frequency [Hz] | The propagation time of a fiber optic telemetry system [μs] | Total delay introduced by the transmitting and receiving system of a fiber optic telemetry system [μs] |
| 100 | 35,0 | 30,3 |
| 200 | 36,5 | 31,8 |
| 300 | 40,0 | 35,3 |
| 400 | 40,0 | 35,3 |
| 500 | 40,0 | 35,3 |
| 600 | 38,0 | 33,3 |
| 700 | 36,0 | 31,3 |
| 800 | 40,0 | 35,3 |
| 900 | 42,0 | 37,3 |
| 1000 | 40,0 | 35,3 |

On the basis of the refractive index in the optical fiber core and its length and speed of light in a vacuum,

the propagation time of the optical fiber used was determined. Based on the obtained oscillograms, the propagation time of a fiber-optic telemetry system was determined, followed by the total delay introduced by the transmitting and receiving system of the fiber optic telemetry system (Table 2.).

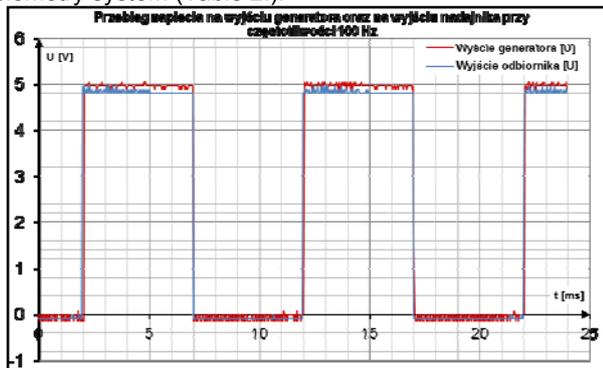


Fig. 14. Oscilloscope of the signal at the input and output of a fiber-optic telemetry link at 100 Hz [own results]

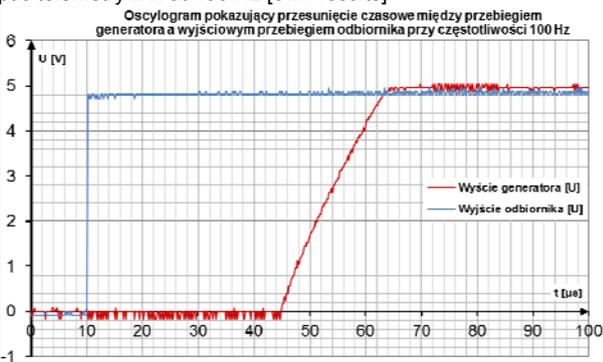


Fig. 15. Oscilloscope of the signal at the input and output of a fiber optic telemetry link at 100 Hz, allowing to determine the propagation time of a fiber optic telemetry system [own results]

Conclusions

On the basis of the tests carried out, the results obtained and the calculations made, it can be stated:

- the mean values of the measured optical power level of the signal (relative reference power level and relative power level of the received signal) fall within the calculated confidence intervals, therefore they can be used to calculate the average fiber damping and the optical fiber unit attenuation,
- the value of the calculated unit attenuation of the optical fiber cable forming the telemetry link, is in accordance with the theoretical value for a single mode telecommunications fiber optic marked as G.652 in the II optical window,
- TTL waveforms (Fig. 14.) are reproduced faithfully – no interference is introduced, as a result of a magnetic or electric field, which confirms the theory regarding the resistance of the signal propagated in the optical fiber to the influence of external fields,
- built fiber optic telemetry system introduces a propagation delay that does not exceed 42.0 μs (Fig. 15.). However, the delay introduced by the transmitting and receiving system of a fiber optic telemetry system does not exceed 37.3 μs . The delay introduced by the optical fiber does not depend on the frequency of the propagated signal, but only on the value of the refractive index of the optical fiber core and the length of the optical fiber.

Additionally, on the basis of obtained oscillograms, it was checked whether the constructed fiber optic telemetry link fulfills the condition regarding the transmission of rectangular signals. He says that on the receiving side, the pulse rise time can not exceed 70% of its duration, so that it is detected correctly [1,12]. For rectangular pulses, with frequencies in the range from 100 Hz to 1000 Hz, this condition was met.

The built fiber optic telemetry system is a selective system, because it allows the simultaneous measurement of two physical quantities – temperature and humidity of the environment. In addition, it allows you to send TTL signals at a distance. The transmission between the transmitting and receiving party is carried out in a serial way using a fiber-optic link with a bandwidth of 1 kbps. However, this is not a limitation of the bit rate resulting from the construction of the optical fiber, but from the construction of the transmitter itself. The signals with a frequency of not more than 1000 Hz are transmitted without distortion. Higher frequencies are suppressed before the electrical signal is converted into optical. The optical fiber itself can get much higher bitrates, currently in the order of terabits per second.

The built-in transmitter and receiver systems can also be used in the II optical window of attenuation and attenuation of single mode optical fibers using the transmission (insertion) method.

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