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Compact QCL driver for free-space transmitter

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Abstract. The paper presents investigations of a free space optical transmitter operating with quantum cascade lasers. The main goal of the research was to determine influence of lasers driver parameters on an optical data link performance. Using some commercial driving devices, the laser pulse limitations of power, repetition rate and time duration have been observed. In the paper, the preliminary results of the designed laser driver are described. The driver was developed at the Institute of Optoelectronics, MUT in cooperation with scientists from the Faculty Electrical Engineering, WUT. It is characterized by high current efficiency, high pulse repetition rate, and compact construction. Additionally, the driver also includes a controller of Peltier modules.

Key words: free space optics, laser communication, quantum cascade lasers, laser driver.

1. Introduction

Free Space Optics systems usually consist of two components: transmitter and receiver. They can operate as either integrated or non-integrated devices. In the optical data link, information is transferred as a modulated radiation from lasers or LED diodes. For that reason, the selection of the radiation source is very important. The main factors taken into consideration during the selection process are emitted spectra, optical power, pulses repetition rate, operation conditions and price. The spectral range is determined by an absorption effect of the atmosphere (so-called transmission windows) and weather conditions (e.g. fog, snow, rain). The optical power influences directly on both – the data link range and the level of eye-safe operation.

Nowadays, dynamic progress on quantum cascade lasers applications in FSO systems is noticed. The QC lasers are characterized by high optical power in the Mid-IR and Far-IR wavelength ranges. They can operate in both pulse and continuous modes providing high frequency of modulation [1]. Their spectral range makes it possible to transmit radiation with low atmosphere absorption (in the wavelength ranges of 3–5 μm and 8–12 μm). In comparison with the FSO systems operating at the wavelength of 0.8 μm and 1.5 μm, the scattering effects are also reduced [2].

Although QC lasers were discovered in the 80's, since the last few years a growing interest, associated with their applications, has been observed [3]. With the technology of MCT detectors operated in the LWIR spectral range, they are an important stimulus for the development of data links operating at the wavelength of 10 μm [4]. However, the application of QC lasers requires to construct special supplying and cooling systems. Compared with semiconductor lasers, QCL power systems ought to supply significantly higher values of both currents and voltages. Such a high level of driving currents also generate large amounts of heat [5]. Hence, it is so important that the design of cooling system consisted of a heat sink, Peltier cells and the TEC controller. Actually, there are a number of commercial drivers dedicated to QC lasers [6–8]. They are fabricated in the form of circuits or OEM systems (Original Equipment Manufacturer). However, their primary limitation are a low level of both output voltage and output current, and the frequency bandwidth.

2. FSO transmitter

Two constructions of the FSO transmitter with QC lasers have been designed at the Institute of Optoelectronics, MUT [9, 10]. The main elements of the transmitters are optical radiation sources (QC laser), collimating optics, laser driver kits, cooling system, data interfaces and mounting platforms [11]. As a radiation source, the commercial available laser systems from Alpes Lasers and Cascade Technologies companies were applied. Each of these systems has characteristic advantages such as an integrated construction (Cascade Technologies), or ability to operate in the CW mode (Alpes Lasers SA), as well as drawbacks such as low radiation power, low pulse repetition, low fill factor (Cascade Technologies) or a complex structure (Alpes Lasers SA). The view of the FSO transmitter with the laser system from Alpes Lasers SA company is shown in Fig. 1.

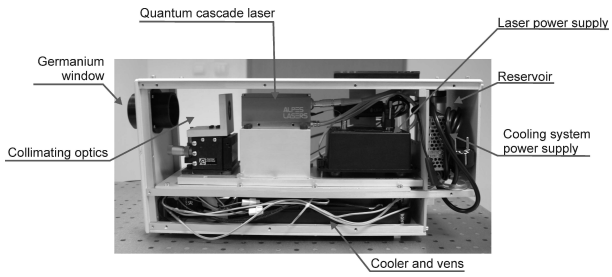

Fig. 1. Photo of the FSO transmitter with QC laser system from Alpes Lasers

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The construction of Alpes Lasers driving unit is based on a commercial current control circuit 1720 PCO model offered by IXYS Inc [8]. The compact construction, simple pulses control (level, repetition and duty cycle) and a range of currents adjustments are the main advantages of the unit. But the application of this unit requires multiple external devices such as two stable voltage supplies and a pulse generator.

3. Transmitter investigations

In the case of FSO systems, both amplitude and stability of the peak power of optical radiation are very important. Therefore, the first study of the transmitter operation was to determine influence of the pulse time parameters (repetition, duty cycle) on the optical pulse shape using the commercial current control circuit 1720 PCO. Figure 2 shows an example of the registered signals using the detection module with MCT detector (produced by VIGO System S.A.).

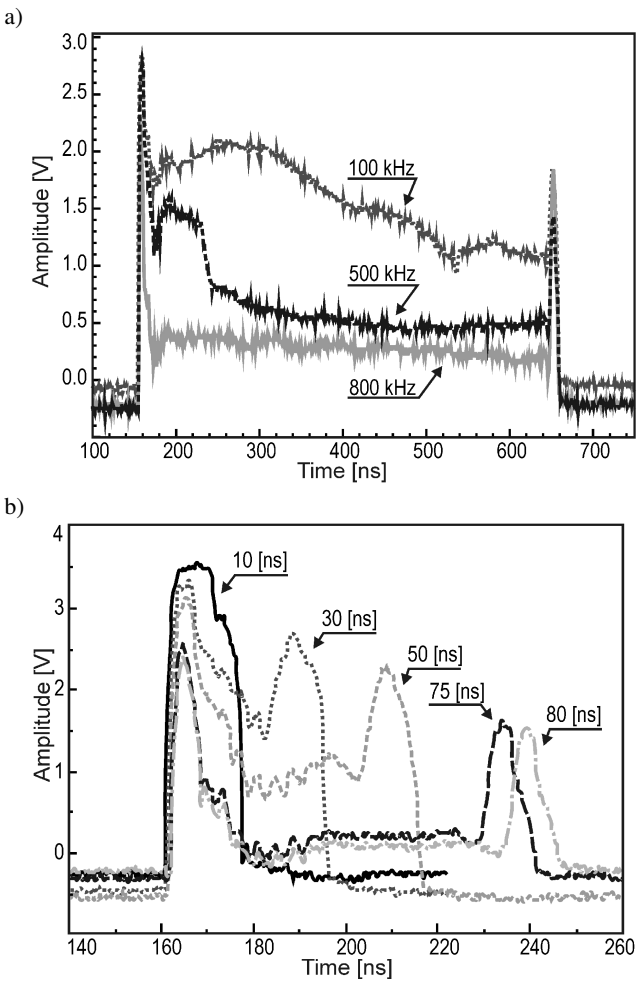

Fig. 2. The shape of optical signals registered with detection module (PVI-4TE-10) for pulse duration of 500 ns (a), and for different pulse duration with constant repetition rate of 5 MHz (b)

There can be observed two factors that affect the shape of the emitted pulses from the QC laser. First one is the characteristic of the specific laser and the second one is the connection wires. Due to the rapid changes in the signal level, there is noticed the impact of wave propagation in the wires. This is particularly observed in the shape of both rise and fall edges of the pulse. Although the connection between the current driver and the laser structure is made using a low-impedance line, its length results in considerable fluctuations. In addition, during the pulse time, a decrease in pulse power of laser radiation is noticed. This phenomenon may be due to dynamically changes of a laser operation point caused by temperature increasing of its structure, and limited parameters of the current driver. With a low level of current efficiency, a decrease in a pulse amplitude with increasing the duty cycle can be observed.

During the second investigation step, the influence of both the laser operating point (current level) and time parameters of control pulses (pulse duration, type of encoding) on the shape of optical radiation pulses was analyzed. Figure 3 shows examples of recorded signals.

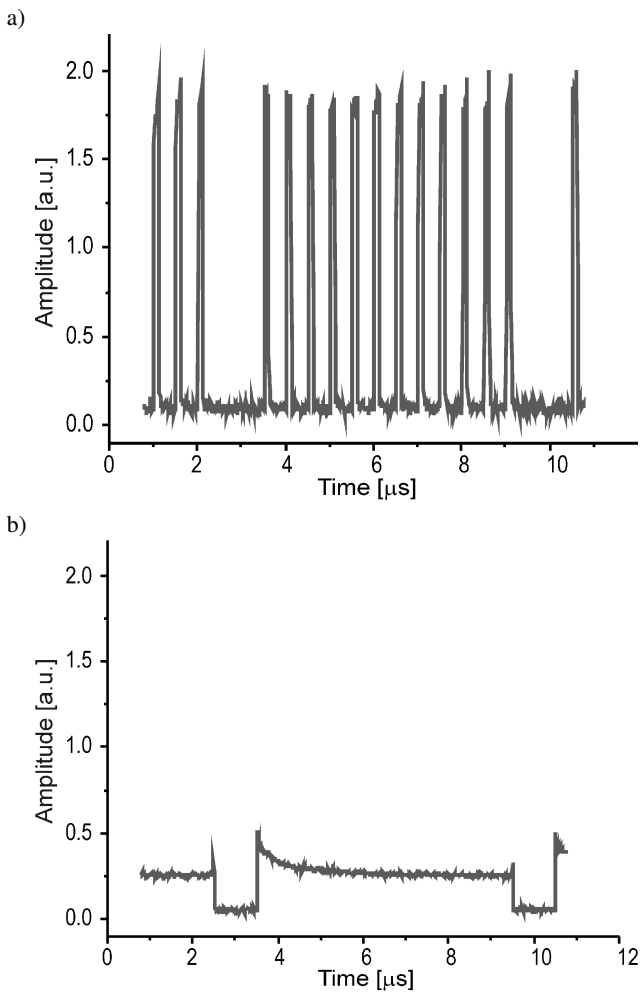

Fig. 3. Examples of registered optical signals for RZ (a) i NRZ (b) encoding

The analysis of the investigation results of the control system and the QC laser shows, that:

- for the constant value of a pulse duty cycle, the increase in frequency causes a decrease in the laser peak power,

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- reducing the duty cycle increases the laser peak power,
- bit error ratio (BER) increasing for very low pulse duration and high frequencies(in case of higher data transmission rate), because of the random pulse disappearance,
- use of NRZ encoding can significantly reduce the value of average power and pulses amplitude.

To perform a simplified analysis of QC laser driver influence on the FSO data link performance, the formula for the bit error ratio value versus signal to noise power ratio (S/N) can be used [12]

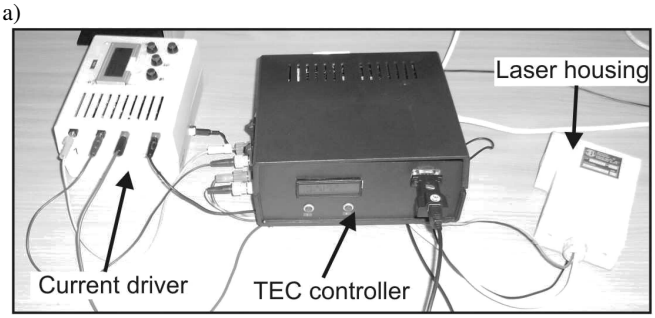
$$BER = \exp\left(-\frac{S}{N}\right) \cdot \left(4 \cdot \pi \cdot \left(\frac{S}{N}\right)\right)^{-1/2}. \qquad (1)$$

The expression is correct for polar NRZ encoding. Studies have shown that in the case of the Alpes Lasers driver, the value of radiation power depends on the time parameters of laser pulses. Based on the obtained results it can be seen that increase of 300% in a pulse duration, causes a decrease of 60% in the received power. At the same time, a change in the BER value from 10^{-15} to 10^{-13} was observed. To ensure an adequate level of the BER, a great decrese in the distance between the transmitter and receiver was required. Similar analyzes were performed with the pulse frequency increasing.

4. QCL driver project

The performed study of the FSO transmitter with commercial QC laser driver showed that the main drawbacks of the QCL driver are: a complex construction, the limited bandwidth and low level of an output current. For that reason, a new driving system has been prepared. The view and block diagram of the driver is shown in Fig. 4.

a)



b)

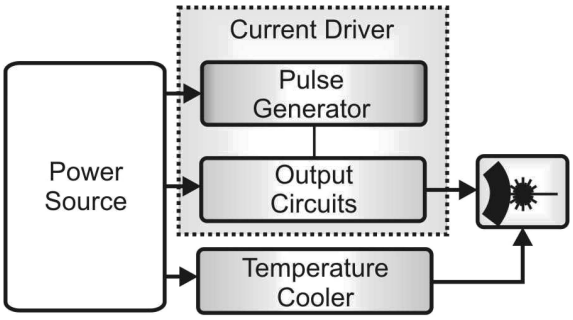


Fig. 4. The developed driver system photo (a) and its block diagram (b)

The main part of the system is a current driver and the temperature cooler (TEC controller). The current driver module consists of a pulse generator and output circuits (the microprocessor control system, an integrated power unit). The control system provides a change of time duration of the generated pulses and their repetition rate. It is clocked applying a quartz generator with the frequency of 50 MHz. The driver uses TTL circuits enabling generation of short pulses characterized by a low value of both rise and fall times. An important element of the current driver is the output power unit consisted of two commercial integrated drivers, both iC-HG types [13]. The first one operates as a current source controlled by a voltage signal and the second one works in a continuous mode and provides to bias the laser structure. The value of a biasing current can be easy set by a user as well. The module can also generate a set number of pulses and work continuously. The main parameters of the constructed current driver are summarized in Table 1.

Table 1
The main QCL driver parameters

Parameter	Range	
Pulse duration	min: 20 ns	max: 5 μs
Repetition rate	min: 6.25 kHz	max: 25 MHz
Programmable number of pulses (burst mode)	min: 1	max: 65536
Peak current (@25MHz and 20ns)	min: 0.1 A	max: 5A

As it was shown, the QCL driver system is equipped with a TEC controller. It uses thermoelectric cells with the total power of 240 W. This system is characterized by the possibility of cooling (minimum temperature is $-30°$C) and heating (up to $50°$C) operation. The cooling system consists of a temperature measurement block, Peltier cells, controller, and water cooling circuit for the cells. For each cell, there is implemented a temperature control unit with programmable adaptive procedures – PID type. Such a solution was applied taking into account not only a level of generated heat but also its dynamic changes. Original solutions for "enhancing" the dynamic characteristics and the temperature operating range of the cooling system were applied.

5. Preliminary reserach of the designed QCL driver

The main task of the developed QCL driver system investigation was to determine its operating characteristics. During the investigations, some electrical QC laser models built of RC circuits with parameters given by Alpes Lasers SA were applied [14]. For the construction of the models, ceramic capacitors and specially made non-inductive resistor have been used. The resistor was made from a copper tube filled with an insulated constantan conductor. Changing the number of lines it was possible to set the value of resistance. In the study, the experiments with the use of commercial resistors (with significant inductance) and the PLC-type laser diode 445LD-A-000 were also performed. The output voltage signals from the

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driver were registered using oscilloscope (Tektronix 4000 series) with two voltage probes (differential measurement) and a current probe (CT-2 Tektronix). The shapes of the registered pulses for the QCL equivalent electrical circuit and a laser diode are shown in Fig. 5.

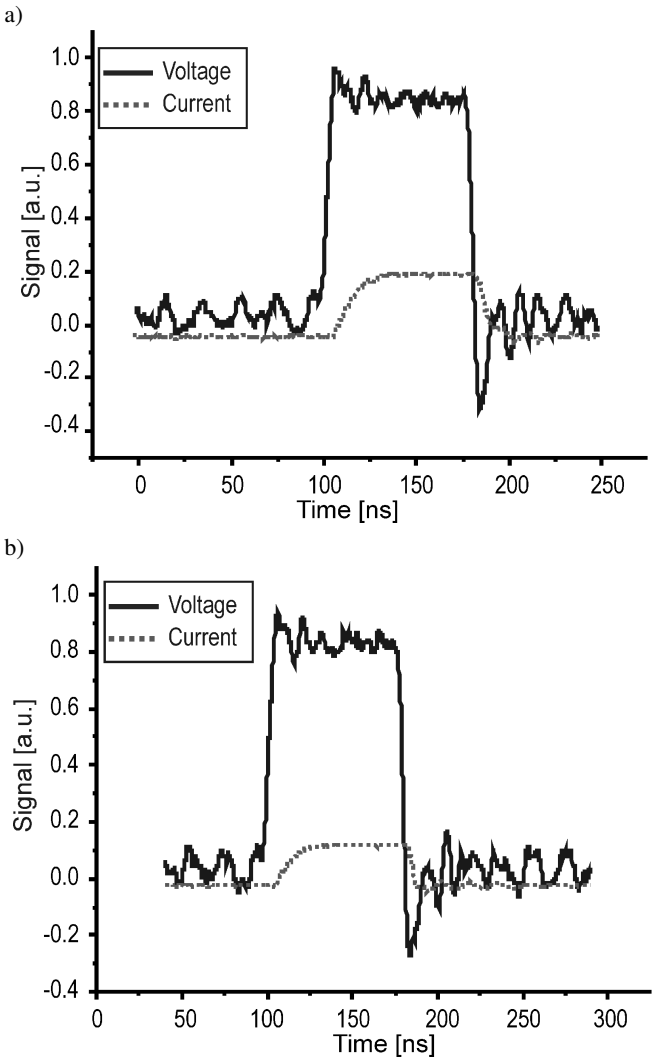

Fig. 5. The shape of the current and voltage signals for electrical model of QCL (a), and laser diode (b)

The signals were recorded for the most critical operating point of the driver system (generation of pulses shorter than 50 ns and the duty cycle of 30%). For the electrical model of the QC laser, the rise and fall times of pulses are respectively 5.4 ns and 3.1 ns (voltage signals), and 16.8 ns and 13 ns (current signals). While for the laser diode current, these times are 15.8 ns and 4 ns. There are also some oscillations of the voltage during power transistor switching. This phenomenon is mainly a result of the voltage measurement method which uses a differential method with two voltage probes. These oscillations are not observed in the case of the current signal. During the research, a few current-voltage characteristics of three type of elements were also determined (Fig. 6). For example, investigations of the laser diode (A, B) for two values of pulse durations (20 ns and 2 μs) and the QC laser models were performed. For the analyses of QC laser driving, two QC laser models were built of non-inductive element with resistance of 3.3 Ω and 1 Ω (C, D).

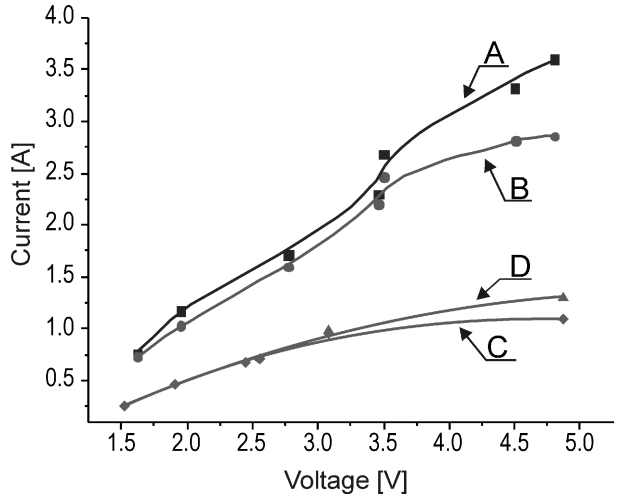

Fig. 6. Measured current-voltage charactersitics for: laser diode driven with different current pulses (A: t_i= 20 ns and B: t_i= 2 μs) and two QC laser models with resistance of 3.3 Ω and 1 Ω (C,D)

The results show the dependence between the value of the generated peak current and the resistance value of the driver load. It may be also noticed that increasing of the pulse duration results in a slight growth in the peak current. But the shape of the characteristics deviates strongly from the straight line. This may be caused due to both a cut-off frequency of the applied signal probes and an influence of "non-defined" circuit inductance. For the short current pulses with high amplitude, the inductance becomes very important.

Figure 7 presents the shape of current pulses at the driver load circuit for several values of the setting current. The measurements were performed also for the QC laser model (Fig. 7a) and the laser diode 445LD-A-000 (Fig. 7b).

During the last step of the researches, a unit designed for temperature control of laser structures was examined. It was performed to verify its proper operation and to determine its characteristics. Dynamic characteristics of the unit for both cooling and heating processes were measured. Figure 8 shows the temperature changes of the two layers of cells (cold and warm) biasing with currents resulting from the selection of the optimum operating point.

Analyzing the obtained characteristics it can be seen that the minimum temperature of $-30°$C is reached at after 150 seconds from cooling start. For heating process, only 40 seconds is required to get the temperature of 50°C. Investigations show that the TEC controller provides the temperature stabilization accuracy below 1.5 K.

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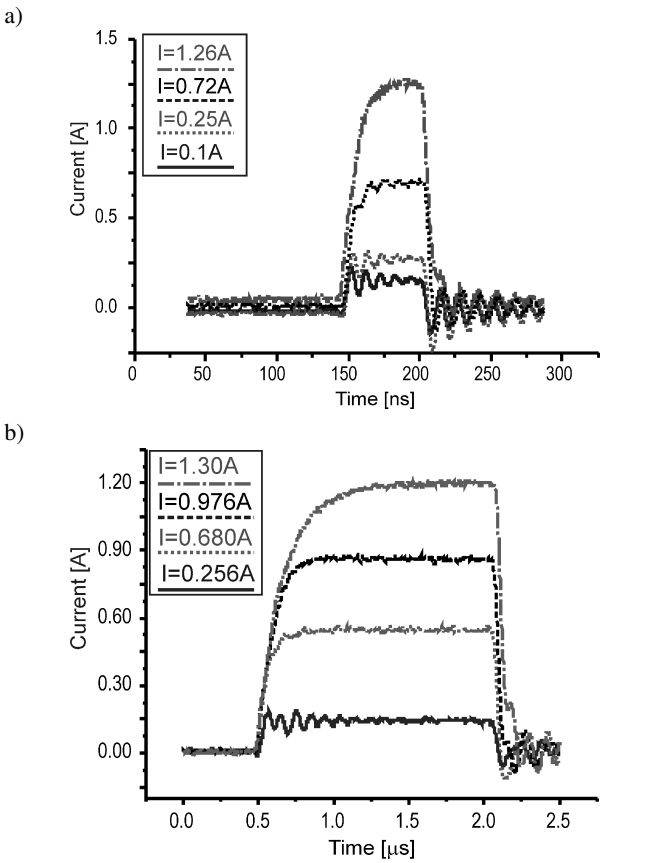

Fig. 7. The shape of currents pulses regidtered for QC laser model (a) and laser diode (b)

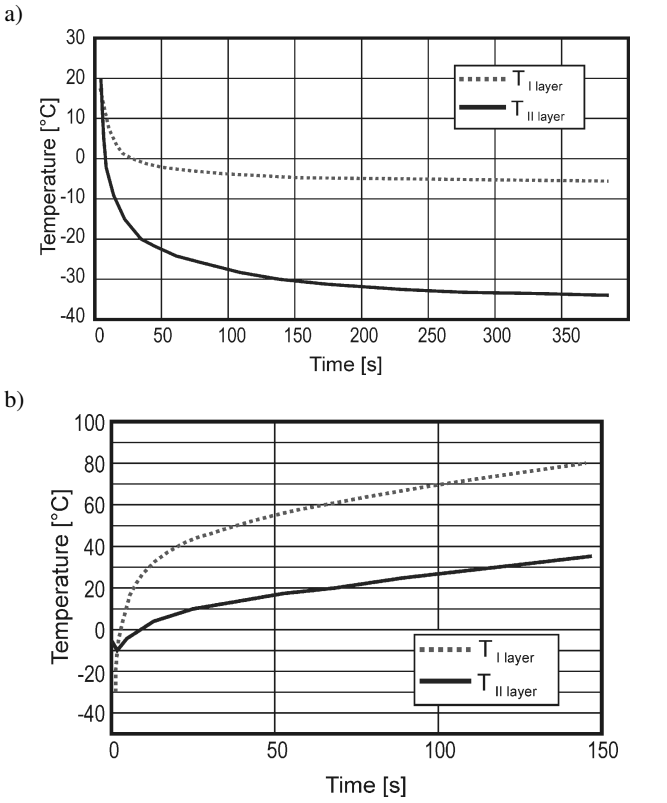

Fig. 8. Dynamic thermal characteristics during procedure of: cooling (a) and heating (b)

6. Summary

The article presents the results of preliminary research of the QC-FSO transmitter, which uses the commercial current control circuit. Studies have shown a strong correlation between shape of optical pulses and the laser operating conditions, in particular, the pulse duration and the repetition rate. Increasing in a pulse duration, a decrease in radiation power was observed. It was caused by temperature raising of the laser structure. This phenomenon cannot be simply eliminated because of the thermal characteristics of the laser operation. The characteristic is dynamically changed with the pulse duration and repetition rate. In the case of the short driving pulses, the level of dissipated power was not so high, so a cooling efficiency was sufficient. The performed analyses showed that the main limitations of commercial QC laser drivers are too small signal bandwidth, the low level of current and voltage driving signals, and not good properties of connection to the laser. Studies have shown that the mentioned factors can substantially limit some parameters of the FSO data link. The developed QC laser driver system is characterized by appropriate signal parameters (high level of amplitude of current, pulse duration and its repetition rate), and excellent utility properties (integration of a supply system with a pulse generator and with a cooling unit). Preliminary examinations have confirmed that the developed system can be effectively used for the generation of short current pulses with the high amplitude and frequency. However, an important phenomenon in the design of this driver is to minimize wave reflections effects associated with applied control signals. Therefore, the further work will develop a suitable technology of connecting driving signals to the QC laser structure.

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