Laser warning system as an element of optoelectronic battlefield surveillance

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ABSTRACT

Detection of laser radiation by the warning system may indicate an attempt to track by a certain type of weaponry. Obtaining information about this intention increases the chances of the protected vehicle surviving on the battlefield. Depending on the type of threat and the equipment of the protected vehicle, various defense scenarios can be implemented, e.g. placing a smokescreen, maneuver to avoid hitting. Information about location the source of laser radiation can be automatically transferred to the weapon system and to convey this information through the battlefield management system to other platforms nearby. This information can be used by these platforms to locate and neutralize the source of danger. The warning system to fulfill its functions, it must detect the sources of laser radiation and should be resistant to optical interference. Considering the characteristics of the laser beam and the propagation of laser radiation in the atmosphere, the sensors of the warning system should work in the optical spectrum defined by laser sources, compensate for the signal dynamics resulting from the variable power of the sources and the distance between the radiation source and the warning system. The warning system as an element of the optoelectronic surveillance system should be equipped with a database of signatures of optical signals occurring on the battlefield (laser sources and interferences). Systems on the protected platform should be integrated to ensure aggregation obtained information and, in this way, improve the probability of threat detection and reduce false alarm probability.

Keywords: laser warning system, detection of laser radiation, laser radiation propagation, laser rangefinder, laser designator.

1. INTRODUCTION

The modern battlefield is well equipped with optoelectronic observation devices ranging from optical devices such as binoculars, optical sights, to night-vision devices, thermovision devices and cameras operating in the visible band of wavelengths. Modules containing laser radiation sources are often integrated with observation systems. They perform various functions: distance measurement (laser rangefinders), target designation (laser designators to guide grenades, rockets, bombs), object illumination (laser illuminators, laser pointers, laser dazzlers, night vision devices) or guiding the rocket by a laser beam (laser beam riders). For this reason, sea, land or air combat platforms are equipped with laser warning systems that allow to monitor the space around and detect threats in advance. Acquiring information about a threat enables to give an appropriate response and thus increases the platform's ability to survive on the battlefield. The system monitors the space in the optical band, detects, analyses and determines the location of the laser radiation emission source relative to the protected vehicle. The analysis of the received optical signal consists in the elimination of optical interference and determining the type of laser radiation source, and thus the hazard classification. The system alerts the crew of the protected vehicle and enables to counteract. It may consist of placing a smokescreen, placing a thermal imaging curtain, activating dazzling measures and disrupting the opponent's optical equipment, or using weapon systems placed on the protected platform. The laser warning system is a passive system, which means that it emits no radiation. In the presented work, the requirements for the laser warning system will be discussed, together with their justification.

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2. LASER RADIATION WARNING SYSTEMS - TYPES OF HAZARDS AND FUNCTIONAL REQUIREMENTS

Functional requirements for the laser warning system are based on the threats that the system should detect and the manner of expected response. To describe in more detail the requirements for the warning system, consideration should be given to the types of hazards as well as sources of optical radiation and their parameters

2.1 Sources of laser radiation on the battlefield

- Laser rangefinder (LRF)

Rangefinders can be classified according to the power of the emitted laser radiation, and therefore the size of the echo signal, distinguishing rangefinders with direct reception and rangefinders with sub-noise reception. Another possible classification results from the maximum range of distance measurement. There are short range laser rangefinders up to 3 km, medium range laser rangefinders up to 5-6 km, long range laser rangefinders up to 10-12 km and very long-range laser rangefinders up to 20 km and more. In the case of rangefinders with direct reception, the power emitted by the transmitters of such rangefinders depends on the measured distance and are in the range from several hundred kilowatts to several megawatts. In the case of sub-noise reception rangefinders, the power emitted by their transmitters is from several to several dozens watts. In rangefinders, laser transmitters generating radiation at 905 nm, 1064 nm and 1510-1550 nm are used most often. In the 70s/80s, attempts were made to build rangefinders at a wavelength of approximately 10 µm. It was initiated by the possibility of using thermal imaging cameras operating in the 8-12 µm band to observe the battlefield. Optical radiation in this range perfectly propagates in the atmosphere even in difficult environmental conditions (fog, smoke). Rangefinder working at a wavelength of about 10 µm can be a great addition to observation and allows to open fire even in difficult weather conditions. Unfortunately, the only laser source generating this wavelength at that time was a CO_2 molecular gas laser. The operation of this laser in the field was so onerous that it was abandoned that such systems would be more widely implemented. Until now, a radiation source generating 10 µm that would meet military requirements has not been developed. Semiconductor cascade lasers give some hope. There are publications describing attempts to use QCL laser matrices in beam guidance systems. An important parameter of the laser radiation sources is the divergence of the laser beam. For most applications it is in the range of 0.5 to 3 mrad. Beam divergence limits rangefinder range. The smaller the divergence, the greater the range. Beam divergence and laser transmitter power have a direct impact on determining the sensitivity of the detection elements of laser warning systems and on how sensors are arranged on the surface of the protected platform. A different issue related to the use of laser rangefinders is eye safety. Rangefinders working in the range from 400 nm to 1400 nm meet this requirement if the laser source powers do not exceed a few to several dozens watts, for pulses from a few to several dozens ns. Laser transmitters with a radiation wavelength of about 1500 nm are considered safe if they emit power up to several megawatts for single pulses or hundreds of kilowatts for transmitters working with low pulse repetition rates.

- Laser designator (LD)

Laser designators are devices that generate a beam of radiation designating an object to which a specific type of warfare agent is directed. Most often these are rockets, bombs or grenades guided by scattered radiation of a laser spot designating the target. The guidance range is generally around 3 km, with the designating laser being at far greater distances. A critical parameter for guidance accuracy is the size of the laser spot focused on the designated object. Too large spot deteriorates accuracy and maximum guidance range. The pulsed laser radiation of the laser designator is frequency-coded, which prevents interference or diversion of the warfare agent by another source. Hence the process of ensuring the distribution of codes of cooperating parties is necessary. Laser designators can be placed on air, land and sea platforms or as equipment of a single soldier. A land platform can designate a target on an air platform and vice versa. All combinations are possible including target designation by platforms of the same type (e.g. air - air). The designators use lasers generating radiation at a wavelength of 1064 and about 1500 nm and with divergence of laser beams below 0.5 mrad. The generated powers reach up to several MW, while ranges up to 20 km.

- Laser Beam Rider (LBR)

In laser beam riders, laser radiation is used to illuminate the back of the rocket. At the back of the rocket there is a laser radiation detector that analyses the received radiation and introduces corrections to the ailerons to change the rocket's flight path. The laser beam illuminating the rocket is coded in cross-section area, hence the signal analysis system introduces corrections to the rocket's flight path, bringing the rocket to the centre of the laser spot. The size of the laser spot illuminating the back of the rocket is almost constant, hence the laser beam control system changes its divergence depending on the distance from the launcher. Beam divergence varies from several dozens degrees to several mrad. Mainly wavelengths of 905 nm and 1.064 μm are used in laser beam riders. The signal repetition is on the order of several kilohertz while laser power on the order of several watts.

- Laser illuminator

Laser illuminators are devices illuminating the scenery for night vision devices and day light observation cameras (detection matrices of these cameras are built on Si detectors, therefore their sensitivity spectrum includes near infrared radiation up to approx. 1100 nm). Near-infrared lasers operating at 850 and 905 nm, with power from 50 to 200 mW and adjustable beam divergence from 0.35 to 960 mrad are used as radiation sources.

- Laser pointer

Laser pointers are devices most often integrated with the soldier's personal rifle but also appears as independent devices. Integrated with the rifle, they are most often used to fire "from the hip" when the aiming point is marked with a laser dot aligned with the weapon's aiming line. In other applications, they are used to indicate targets for various armament units. If there are more targets indicated in the field of view, the frequency modulation of the generated radiation is used. Then, the appropriate armament units are assigned to each frequency. The laser pointers use visible (green, red) and near infrared radiation. The laser beam divergence ranges from 0.1 to 0.5 mrad while the laser powers from 50 to 250 mW. The laser pointers generate continuous or modulated radiation with a frequency of 1 to 10 Hz.

- Laser dazzler

Laser dazzlers are used to make it difficult for an opponent to open fire by emitting radiation that causes glare. Mainly lasers generating green or red radiation are used for dazzling people. Infrared radiation is used to dazzle or damage optoelectronic equipment. The divergence of the beams generated by laser dazzlers ranges from 0.5 to 960 mrad. Usually, optical systems used in dazzlers can change the divergence of the laser beam and scan the space with the beam. The scanning angles are up to several dozens degrees. The information discussed above regarding the sources of laser radiation is summarized in Table 1. The shape of some beam spots generated by laser transmitters are shown in Fig. 1.

Table 1. Information regarding the sources of laser radiation

Lase radiation source at a battlefield	**Wavelength [nm]**	**Optical power [W]**	**Divergence [mrad]**	**Shape of beam spot**
Laser rangefinder (pulse generation)	905	several – over a dozens	0.2 ÷ 2	A, B, C, D, E, F
	1064	several 10^6		
	1540	several – over a dozens 10^6		
Laser designator (pulse generation)	1064, 1540	several 10^6	0.2 ÷ 0.5	F
Laser pointer (cw or pulse generation (10Hz))	visible (532, 650), infrared (850)	0.05 ÷ 0.25	0.1 ÷ 0.5	C or F
Laser beam rider (cw generation, cross-section modulation)	infrared	several – over a dozens	depends on the distance	F with cross-section modulation
Illuminator (cw or pulse generation)	850	0.05 ÷ 0.2	0.35 ÷ 960	C or F
Dazzler (cw or pulse generation)	people -visible (532 650), equipment – infrared (850)		0.5 ÷ 960	C or F

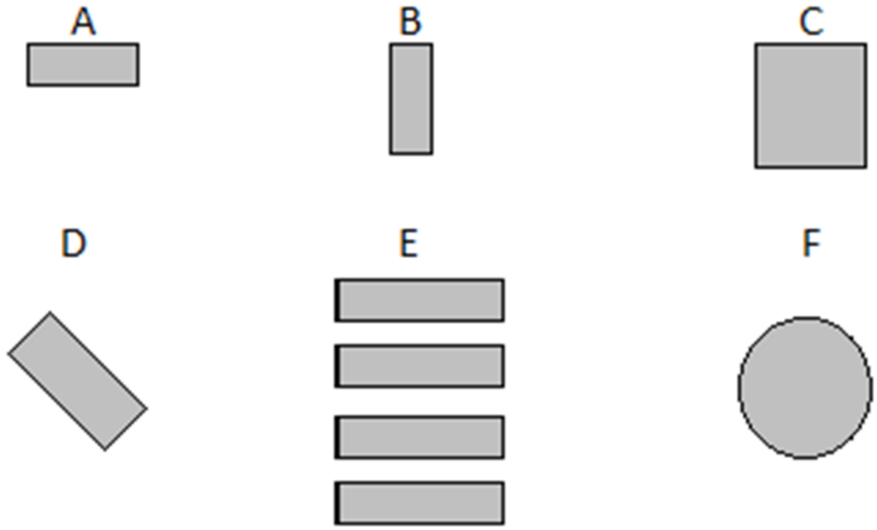

Figure 1. Shape of some beam spots generated by laser transmitters.

2.2 System sensitivity requirements

Analysing situations on the battlefield, it should be noted that high-power lasers are mostly used in systems designed for distances to the target greater than 1000 m. Systems equipped with such sources, firing up to 1000 m, do not introduce ballistic corrections related to distance, and operators of laser designators also try to be as far as possible from the designated target for safety reasons. Thus, a minimum distance of 1000 m can be assumed. The maximum distance should be defined by the maximum working range of the system. The maximum ranges of systems based on high power lasers are in the range of 10-20 km. Assuming that the laser spot will have a circle shape and a homogeneous power distribution, one can estimate the power density incident on the detectors of the laser warning system using the following equation:

$$P_d = \frac{4 \cdot P_0 \cdot e^{-\gamma R}}{\pi \cdot R^2 \cdot \theta^2} \; [W/m^2] \tag{1}$$

where:

P_0 – transmitter output power [W];
R – distance from transmitter [m];
γ - atmospheric extinction coefficient [m^{-1}];
θ – beam divergence [mrad];

Carrying out simple calculations and assuming laser power of 3 MW and beam divergence of 0.5 mrad, the obtained power density incident on the detectors of the laser warning system for high power sources is about 15 MW/m^2 at 1km and about 38 kW/m^2 at 20 km. In the case of low power sources (power of 8 W and divergence of 1mrad) the minimum distance range is approx. 500 m, and the maximum between 3÷10 km, hence the expected power densities on the detector, as a function of the target distance, are approx. 40 kW/m^2 at 500 m, 1 W/m^2 at 3 km, 0.4 W/m^2 at 5 km and 0.1 W/m^2 at 10 km, respectively. These simple estimates show that the detectors of the laser warning systems should detect signals for the power density in the range between 0.1 W/m^2 and 15 MW/m^2. Using the InGaAs detector, one can cover the entire wavelength band generated by laser transmitters while the Si detector will detect 905 nm and 1064 nm wavelengths. A useful parameter that can help to estimate the detector's detection capabilities is the NEP parameter. Assuming InGaAs photodiode detector with a detection surface of 1mm^2 the average NEP parameter is $1.9 \cdot 10^{-14}$ $W/Hz^{1/2}$. Assuming the band B = 50 MHz, SNR = 10 and not considering the power of background radiation and noise of the amplifier the minimal detectable power density incident on the detectors of the laser warning system can be expressed as:

$$P_{dmin} = SNR \cdot NEP \cdot \sqrt{B} \cdot 10^6 \;\; [W/m^2] \tag{2}$$

and is equal to 1.3 mW/m^2. The obtained value means that it is possible to detect even the weakest signals. In the design of the detector of the laser warning system, the issue of dynamics of received signals and limitation of the power of background radiation should be solved. Background radiation for the 900 nm spectral range is approx. 600 $W/m^2\mu m$ and for 1500 nm approx. 100 $W/m^2\mu m$. The above calculations assumed a homogeneous power density distribution in the cross-section of the laser beam. In fact, real distributions differ significantly (Fig. 2). For high quality lasers this distribution is described by the Gauss function, which means that in the middle of the laser beam the power density is the highest and, on the edges, the smallest. The parameter describing the optical quality of the laser beam is the M2 parameter, which specifies the degree of deviation of the real beam from the Gaussian normal distribution. The power density distributions presented in Figs. 2 show that in real conditions the assumed power densities may significantly exceed the calculated threshold values or be below these values. A small change in the position of the laser spot on the object is enough for these values to change. This situation has both good and bad sides. Low power laser transmitters can be detected at greater distances than calculated, but in other cases radiation may not be detected despite that the power density on the detector will be well above the detection threshold. More information on the phenomena occurring during the propagation of optical radiation in the atmosphere can be found in [2].

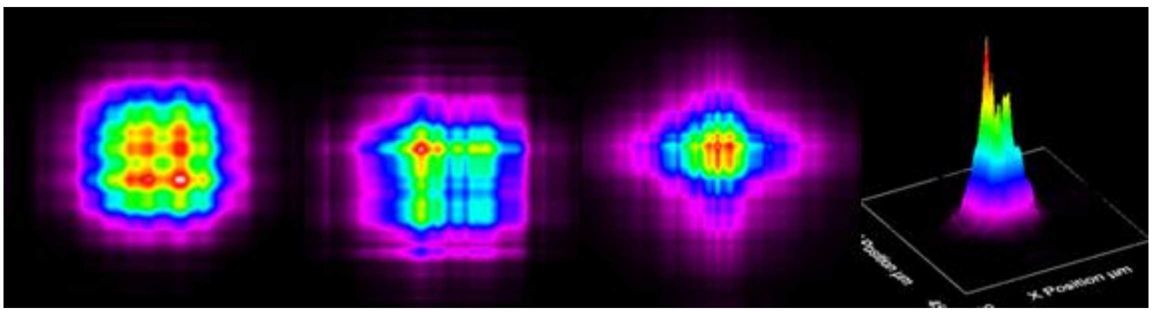

Figure 2. Examples of power density distribution in a laser beam.

2.3 Requirements for the range of detected wavelengths

The detector of the laser warning system should detect all wavelengths of laser radiation sources present on the battlefield, but at the same time should be resistant to optical interference such as explosions, flames, flares from natural and artificial sources. Taking these aspects into account, the detector should be built of many sensors enabling spectral analysis of received signals, considering their time characteristics. An important question is whether the laser warning system should detect laser pointers and dazzles. Some systems have such a possibility, however, considering the divergence of beams and the ranges of these devices, one should doubt the effectiveness of detection of this type of laser sources. In addition, these devices generate radiation in the visible spectrum and therefore this type of source can be detected by the naked eye.

2.4 Requirements for the accuracy of determining the angular location of the laser radiation source

The accuracy of angle determination should result from the possibility of using this information [1, 3]. If the protected vehicle is not equipped with any countermeasures, determining the sector where the source is located with an accuracy of 90° seems enough. If the protected vehicle is equipped with a smokescreen option, this accuracy should be in the order of over a dozens degrees, and if in an automated weapon module, this accuracy should be at least in the order of several degrees. The standard military vehicle is about 8m long, which means that at 1km it has an angular dimension of approx. 0.5°. In addition, network-centricity of command and the purpose of the acquired information should be considered. Should it be addressed to the vehicle crew and consider its equipment and capabilities, or should it also constitute data, for higher level management of a battlefield with required greater accuracy.

2.5 Arrangement of the system detectors on the protected object

The accuracy of the distance measurement is largely influenced by the stability of the platform from which the measurement is made (from hand, tripod, from the vehicle) and the dimensions, shape and surroundings of the object to which the distance is measured. Therefore, distance measurements are made to the largest surfaces of the object placed as high as possible above the ground. Beams with small divergence are usually generated by high power lasers used as laser designators or very long-range laser rangefinders. The measurement of beam divergence consists in determining the dimension of the beam cross-section, which contains about 90% of energy. The divergence of most laser beams generated by the devices on the battlefield ranges from a few mrad to 0.2 mrad. This means that the size of the laser spot on the protected object at e.g. 1 km can vary from several meters to 20 cm. In practice, this means that if one wants to detect every laser source, the system's detectors should not be more than 20 cm apart. In fact, it is not possible to cover the protected object with so many detectors. Therefore, when designing the system, the specificity of the use of laser devices should be considered. So, even for a 20 cm spot, quite a lot of radiation will be outside this area. So, the conclusion is, that the space between the detectors do not have to be equal to the theoretical size of the laser spot in order to detect it. Of course, this option should be approached with caution.

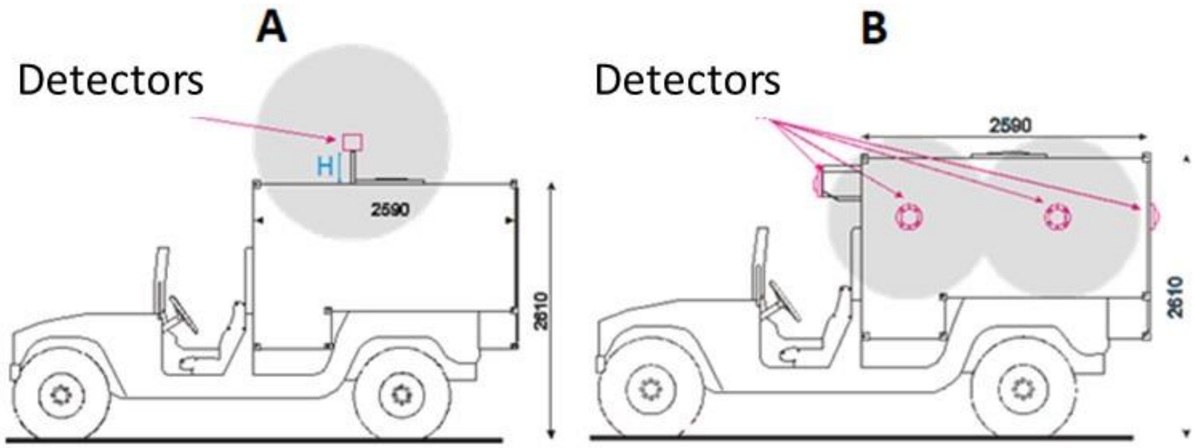

Figure 3. Installation of the laser warning system A) incorrect, B) correct.

Summing up the requirements for the arrangement of the system detectors on the protected object, the detectors should be placed on the upper part of the vehicle, approximately 2/3 of the height of the main body, with the space between them not more than 1.5 m (Fig. 3). They should be able to detect radiation scattered on the body of the vehicle. The latter feature is especially important because it allows to detect laser radiation even if it does not hit the detector directly. It will not be possible to determine the exact direction of the radiation source but the zone in which the radiation source is located will be depicted.

3. SUMMARY

Detection of laser radiation by the warning system may indicate an attempt of tracking down by a certain type of weaponry. Obtaining information about this intention increases the chances of the protected vehicle to survive on the battlefield. Depending on the type of threat and the equipment of the protected vehicle, various defence scenarios can be implemented, e.g. placing a smokescreen (which will impede further tracking), manoeuvre to avoid hitting (abrupt change of direction, using of terrain cover).Information on the location (coordinates) of the source of laser radiation can be transferred automatically to the weapon system from which fire can be opened incapacitating the "radiation source". This information can also be transferred through the battlefield management system to other platforms located nearby. The information can be used by these platforms to locate and neutralize the source of danger. If warning system has to be fully functional, it must detect the sources of laser radiation mentioned above and should be resistant to optical interference. Considering the characteristics of the laser beam and the propagation of laser radiation in the atmosphere, the detectors of the warning system should work in the optical spectrum defined by laser sources. They should also be resistant to the signal dynamics resulting from the variable power of the sources and the distance between the radiation source and the warning system. The warning system as an element of the optoelectronic surveillance system should be equipped with a database of signatures of optical signals occurring on the battlefield (laser sources and interferences).

The database of these signatures should be regularly updated. Based on this information, the laser warning system will more accurately determine the type of threat and will be resistant to interference. Systems on the protected platform should be integrated to ensure aggregation of the obtained information and in this way improve the probability of threat detection and reduce the likelihood of false alarm. The detectors of the laser warning system can be used to identify friend and foe (IFF system) and to transmit data during radio silence.

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