The concept and design of navigation systems based on solid-state and semiconductor lasers

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Abstract. The concept and design of the navigation system based on solid-state and semiconductor lasers is presented. The possibility of using a laser with a self-reversal of a radiation wavefront with a beam quality parameter $M_2 \leq 1.2$ and a single-frequency pulse power of more than 20 MW for constructing a master oscillator of a solid-state laser emitter is considered. The possibility of using a 100 W multi-cell continuous semiconductor laser for constructing a master oscillator of a semiconductor laser emitter with a fiber output is demonstrated.

Recently, more and more widespread use of laser systems for orientation and guidance of various autonomous means. They are designed to determine the location and direction of movement within a sector or zone of orientation, to indicate the required trajectories and designate areas of space with a special mode of movement.

The contrast between the brightness of the output laser radiation and the background of its scattered radiation is maintained at very remote distances, reaching tens of kilometers. Moreover, laser radiation is characterized by a relatively small dependence of the propagation path of its propagation on the features of the terrain. At the same time, the efficiency of laser means is markedly reduced in difficult meteorological conditions (precipitation, fog, etc.) due to a sharp increase (according to the Bouguer-Lambert law) of the absorption and aerosol scattering indicators and, as a result, the attenuation of optical electromagnetic waves. range in a scattering atmospheric environment. It is quite obvious that the atmospheric effect of attenuation of optical radiation can be compensated for by an increase in the power density of laser radiation, which leads to a reasonable application of laser systems in the near-navigation means of moving objects.

In addition, under poor weather conditions in an aerosol atmosphere, only one fixed laser wavelength is less preferable due to strong absorption by the medium compared with a spectrally broadband radiation source. In this case, it is necessary to have two or more spectral emission bands that are little absorbed under these conditions by the polluted atmosphere.

The radio-technical systems designed for solving such problems do not fully meet the increased requirements for the orientation accuracy of moving objects. This becomes especially relevant when controlling the movement of moving objects along complex, non-straightforward paths of motion. Often, the guidance of moving objects is required with an orientation accuracy of more than an order of magnitude greater than the value of the orientation accuracy inherent in radio systems.
Thus, to ensure reliable orientation and guidance, it is necessary to create integrated laser-radio-engineering multi-wave systems.

Conventionally, laser tools for navigation purposes can be divided into non-Doppler and Doppler systems. The advantage is Doppler systems, which, in turn, are divided into continuous and pulse-periodic. A common disadvantage of continuous Doppler laser systems is poor range resolution, the scale of which is comparable to the range itself.

The greatest opportunities are possessed by pulsed laser sources (PLS). For PLS, the probing volume is determined by the duration of the probe pulse and the transverse size of the laser beam.

To date, there are several types of pulsed OR operating at wavelengths of 10.6 μm (built on the basis of a gas CO2 laser), 2 μm, 1.5 μm and 1.06 μm (based on solid-state lasers). The longitudinal size of the sensing volume generated by a pulsed CO2 laser is about 300 m. At the same time, the range resolution will also be several hundred meters, which seems to be too large a value for practical use in this direction. An attempt to improve the spatial resolution (decrease the longitudinal size of the probing volume) inevitably leads to a broadening of the Doppler spectrum and, consequently, to a decrease in the peak of the useful component of the spectral distribution, which in the limiting case can become comparable to noise.

In a laser with a wavelength of λ = 1.06 μm, the energy of the probe pulse reaches 1 J, which allows measurements at distances of up to 26 km. In a laser with λ = 1.5 μm, the probe pulse energy is about 100 mJ, but the pulse repetition frequency is rather high, about 10 kHz, which allows using the accumulation of Doppler spectra over a large number of probe pulses and increasing the accuracy of the Doppler frequency shift. The maximum measurement range of such a laser is ~ 1.5-2 km.

Thus, the highest priority for this direction are pulsed lasers with a wavelength of 1.5 μm and 1.06 μm, 2 μm based on solid-state lasers with narrow-band semiconductor pumping. Such lasers can be installed in conjunction with radio equipment on a mobile wheeled or tracked platform.

It should be noted that the majority of navigation systems based on laser emitters are based on one principle. A typical scheme for building a single channel is shown in Figure 1.

![Figure 1 - Diagram of building a laser navigation system for a mobile platform](image-url)
The radiation of the master oscillator, whose high quality is based on the self-phase-conjugation of the wave front, is amplified by a two-pass or four-pass amplifier, depending on the required level of output energy, and is sent to the sensing region with the help of a telescope. Scattered radiation is collected with a telescope and is fixed by one of two photodetectors. The processing of the received signal is carried out by a special device and is compared with the original signal, which is fed from the master oscillator using the second photodetector.

The design of the navigation system on the mobile platform can be represented, for example, as shown in Figure 2.

As a master oscillator of the first laser channel, we can use a compact solid-state self-phase-conjugated laser system with multiwave interaction in an active (amplifying) medium and a passive Q-switch, in which a dynamic loop cavity is turned on during the generation start.

For lasing with transverse diode pumping, we developed and created a quantron with a laser crystal of Nd:YAG (0.9 at.\% Nd3+) 8 mm in dia and 180 mm in long. The transverse pulse-periodic pumping of active element (AE) was carried out by sixteen matrices of laser diodes of the SLM 3-2 type with a peak power of up to 2 kW each. The matrices were located along the AE in four rows of four matrices in each row. The maximum total pump energy was \( E_p = 14.5 \, \text{J} \).

The optical scheme of the laser is shown in Figure 3. The laser consists of one AE 1, two end mirrors 2, six rotary mirrors 3 and a passive Q-switcher 4 based on a LiF: F2—crystal with initial transmission \( T_0 = 14\% \) (the length of the passive Q-switcher is 51.5 mm). The best results were obtained with a characteristic length \( L \) (Figure 3) equal to 60 cm.
With this arrangement, pulse trains with an energy of 2.55 J and a beam quality parameter $M^2 \leq 1.2$ were obtained with a divergence of 0.35 mrad and a spatial brightness of $7 \times 10^{14} \text{ W/(cm}^2\times\text{sr)}$. The peak power of single-frequency pulses exceeded 21 MW with their energy of 230 mJ. The generation bandwidth was 300 MHz.

In another channel, the master oscillator is built on a continuous semiconductor laser. The optical scheme of a semiconductor laser with a power of up to 100 W has been experimentally tested now. It is based on the summation of the radiation power of 14 polarization lasers: the radiation of a matrix of 7 lasers with $S$-polarization is combined with the radiation of a matrix of 7 lasers with $p$-polarization in the plane of the polarization cube. The power of each laser in the matrix is 8-10 Watts.

Then the combined beam with the help of a collimation-focusing optical system is inserted into the fiber core.

The optical scheme of the laser is shown in Figure 4 and the design of the experimental sample semiconductor laser is shown in Figure 5.
The design of an experimental sample of a semiconductor laser with a power of up to 100 W is shown in Figure 5. The approximate overall dimensions of the laser (Figure 5) are (L×W×H) 120×60×20 mm. Beam quality parameter BPP < 2. The laser radiation from the oscillator is modulated then by an external Q-switcher before being directed to the amplifier.

Since the laser system does not operate with single pulses (single measurement), but in the generation mode of a train of pulses with a kilohertz frequency, by averaging the results, a high accuracy of measurements is quite quickly achieved.
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