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A Novel Laser Target Simulator with High Precision and High Attenuation Rate

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Abstract: In order to simulate the target echo laser signal, we designed a novel laser target simulator with high precision and high attenuation rate used for sensitivity test, function test or tracking mode test of laser receiving equipment, such as Lidar and Laser Range Finder. Regarding the laser receiving equipment on the motion platform, the model of target echo power was established based on the characteristics of laser atmospheric transmissions in the application environment. The simulation shows the model is consistent with the test data. Additionally, the MEMS ESVOA (Micro-Electro Mechanical Systems Electro-Static Variable Optical Attenuator) device was used in the overall solution of the laser target simulator to realize the target echo signal simulation with miniaturization, high attenuation rate and high precision. Finally, a laser target simulator test system was built and its high rate of attenuation, high precision and stability of laser power tested. The test results show that the change rate of target echo signal energy is more than 7×10^4 dB/s, the power simulation accuracy is better than 0.1 dB and the laser pulse power stability is better than 0.61%.

Keywords: high precision; laser range finder; laser target simulator (LTS); MEMS ESVOA

1 INTRODUCTION

Laser Target Simulator (LTS) produced pulse laser signal which simulates the laser echo signal reflected by the target. As an instrument, LTS is widely used in the development of Lidar, laser range finder and other kinds of laser receiving equipment [1, 2]. They are used for sensitivity measurements, function tests, and tracking mode test of laser receiving equipment to test whether the laser receiving equipment can receive the signal and how weak the signal can be when received and processed. So LTS is a simulated laser source developed to emit weak laser for receiving equipment tests. Because the power of real laser echo signals is weak and variable, the power of the laser emitted by LTS is adjustable dynamically. The technical routes of laser power adjustment for LTS mainly include the following types: photoelectric dimming method, ring-actuated iris method, and attenuation elements dimming method [3, 7].

The photoelectric dimming method changes the laser power by adjusting driving current of laser. Therefore, the LTS with photoelectric dimming method has a small dynamic adjustment range and slow speed. Ring-actuated iris method limits the spatial laser beam's aperture to adjust the strength of the passing beam. Since it is difficult to keep the spatial beam uniform, the accuracy of laser power controlled by ring-actuated iris adjustment mechanically is low [4, 5]. The attenuator elements dimming method attenuates the laser by inserting neutral density filters, variable neutral density filters or wedge beam splitter mirror in the spatial light path. This method first produces pulse laser with constant power value which is known, then the laser goes through an attenuator with known attenuation to make weak laser pulse signal. As a result, the attenuator depends on the range, the speed and the accuracy of laser signal. Fixed neutral density filter can only make LTS produce several optical power values with multiple neutral density filter, and variable neutral density filters can make LTS produce gradual laser energy value. However, the attenuation rate and accuracy of the laser signal with gradual attenuator is low, and the range of attenuation is small. The LTS with wedge beam splitter mirror can generate different orders of reflected light by repeated reflections with two surfaces. The beam splitting ratio of each order of reflection light can be calculated according to Fresnel's law and the refractive index of wedge beam splitter [6]. The LTS with wedge beam splitter mirror has high requirements for the degree of laser polarization and the material manufacturing technology of wedge beam splitters. Additionally, actual measurement results deviate greatly from theoretical values. Using the above method, the dynamic attenuation range of LTS is more than 50 dB, the attenuation stability is less than 3%, and the attenuation rate is greater than 20 dB/s. They cannot meet the requirements of testing some quick-moving laser receiving equipment.

To solve the problem of the low speed, large, expensive and small dynamic range of the current LTS, we aim to develop LTS with MEMS ESVOA (Micro-Electro Mechanical Systems Electro-Static Variable Optical Attenuator) as attenuators which can realize high rate of attenuation, high precision and small volume. In order to obtain better simulation results of the laser signal of the motion platform, we established a dynamic model of the echo laser signal power in which the echo laser power can be set automatically according to multiple parameters, such as distance, atmospheric characteristics and irradiation energy. Subsequently, the laser energy control part can set the simulated echo power which matches the above multiple parameters. This technology provides a solution to promote the test method of laser receiving equipment.

2 LASER TARGET SIMULATOR DESIGN

2.1 Laser Echo Power Model

The LTS can generate laser pulse which simulates the echo laser pulse transmitted through the atmosphere to the target and reflected by the target, then returns to the aperture of laser receiving equipment. The echo laser power can be calculated according to the Lidar equation, (Eq. (1)).

$$P_{\mathrm{r}} = \frac{K \cdot P_{\mathrm{t}} \cdot T_{\mathrm{t}} \cdot T_{\mathrm{r}} \cdot \eta_{\mathrm{t}} \cdot \eta_{\mathrm{r}} \cdot D^2 \cdot S}{4\pi \cdot \varphi^2 \cdot R_1^2 \cdot R_2^2}. \quad (1)$$

In the equation, P_{r} (W) is echo laser power; K is laser beam distribution function; P_{t} (W) is laser emission power;

T_t is atmospheric transmittance from the laser to the target; T_r is atmospheric transmittance from receiver to target; η_t is the transmittance of emission optical system; η_r is the transmittance of receive optical system; D (m) is effective optical aperture of the laser receiver; S (m^2) is target laser cross-sectional area; φ (rad) is the beam divergence angle of laser; R_1 (m) is distance from laser to target; R_2 (m) is distance from the target to laser receiving equipment.

When the system works on a motion platform, the echo laser signal changes all the time. In order to simplify the echo laser signal power model, it is assumed that the laser emission power (P_t), the beam distribution function (K), the transmittance of emission optical system (η_t), transmittance of receive optical system (η_r), the effective optical aperture of the laser (D), the target laser cross-sectional area (S), and the beam divergence angle of laser (φ) are constant. This hypothesis is consistent with the working state of most laser receiving equipment such as Lidar. When the platform moves very quickly, the variation of atmospheric transmittance is negligible for the laser receiving equipment. Therefore, the echo laser power is a function of the relative position of the target and Lidar. Therefore, the echo laser signal power can be calculated by Eq. (2).

$$P_r = f(R_1, R_2) \quad (2)$$

The rate of echo laser power change can be calculated by d(P_r) = df(R_1, R_2), when the laser receiving equipment gradually approaches the target.

When the laser receiving equipment approaches the target at 2000 m/s, the change rate of the laser echo power is greater than 1200 dB/s at about 10 m from the target. So the LST with high attenuation rate is necessary.

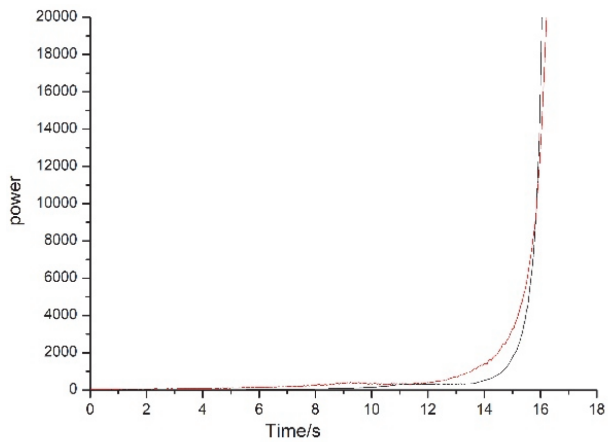
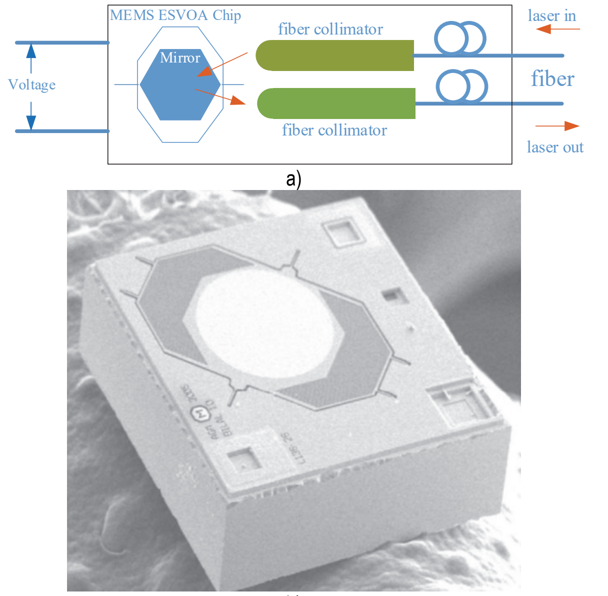


Figure 1 Echo energy signal simulation (black) and field experiment (red) test curves

We use the Eq. (2) to simulate the dynamic echo laser signal power and get the curve like Fig. 1(black). The field experiment test curves with the same speed platform are shown in Fig. 1 (red). These two curves show identical trend, therefore, the theoretical model established in this paper can be used to simulate the echo laser signal power.

2.2 Overall Scheme

In order to get high precision and high attenuation rate echo laser signal, in this paper, the MEMS ESVOA is used as attenuator. The structure of the MEMS ESVOA is shown in Fig. 2. A micro mirror is etched on a silicon-based wafer using semiconductor wafer processing technology. The Angle of light reflection is controlled by electrostatic force. The laser is directed at the micro mirror through fiber collimator. Applying a certain voltage on MEMS ESVOA, the micro mirror will rotate and change the amount of laser reflecting to another fiber collimator, finally controlling the laser energy attenuation.



a)

b)

Figure 2 The structure of the MEMS VOA (a) and chip structure (b)

Due to the MEMS ESVOA has high dynamic rate, high precision and small volume. The LST can follow the change of laser echo power received by fast-moving laser receiving equipment. The LST is composed of laser transmitting system, laser power control system, digital control system, power supply system. The laser is generated by a semiconductor laser, attenuated using fiber MEMS ESVOA and output by beam expanding mirror. The functional block diagram of the LST system is shown in Fig. 3.

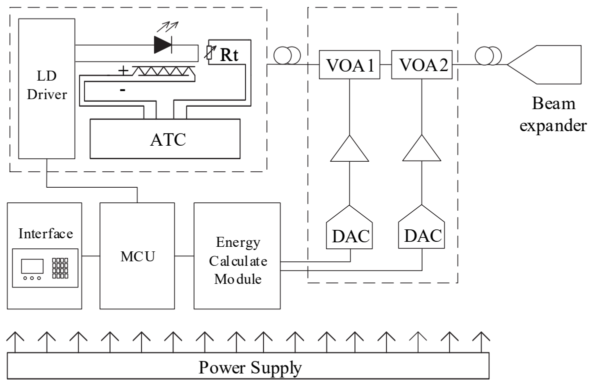


Figure 3 Laser target simulator composition diagram

The function of the laser emitting system is to emit stable power pulse laser as the laser emitting source of the whole system under the control of the digital control system. The laser emitting system includes Laser Diode (LD), LD drive circuit, LD temperature control circuit, LD power control circuit. The LD drive circuit provides current drive for the LD. The pulse power of laser is dependent on the LD drive circuit. LD temperature control circuit controls internal temperature of the LD through current driving Thermo Electric Cooler (TEC) which can heat and cool down the LD. The thermistor inside LD can provide feedback and form a closed-loop to control the internal temperature and the wavelength of the laser. As a result, laser emitting system emits stable laser pulse with a constant power.

The laser power control part is composed of MEMS ESVOA, analog amplifier circuit, digital analog converter (DAC) and connected optical fiber. MEMS ESVOA is a voltage control device. By controlling the voltage of the MEMS ESVOA, the attenuation of laser between the input and output fiber can be controlled. In order to improve the accuracy of attenuation, the MEMS ESVOA calibrates every decibel of attenuation. Two or more MEMS ESVOA can be cascaded to increase the rate and range of attenuation. Therefore, the range of attenuation could be infinite in theory.

3 ANALYSIS AND DISCUSSION

A test system was built to verify the performance of the LTS. Through experiments, the advantages of the LTS, such as miniaturization, high dynamic and high precision, were verified. The actual picture of the LTS is shown in the following Fig. 4.

Figure 4 The picture of laser target simulator

3.1 Experimental Test of High Attenuation Rate of LTS

To verify the high dynamic rate characteristics of the LTS, the experimental test was carried out for the dynamic change of laser power, and the static test and dynamic test of the system were carried out respectively.

First, the static test of LTS was conducted. The laser pulse power is measured by photoelectric detector and acquisition card. The test results show that the energy instability of laser echo is better than 0.39% (1σ).

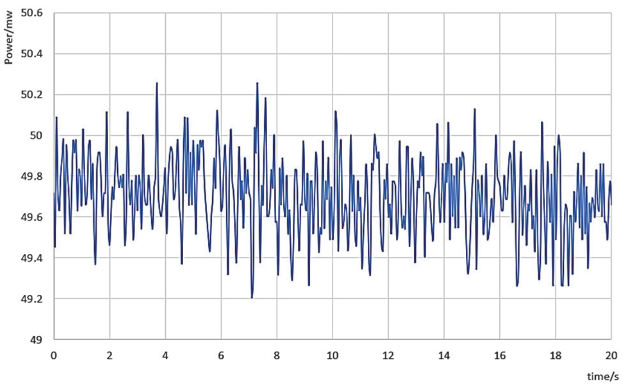


Figure 5 Static test curve of LTS

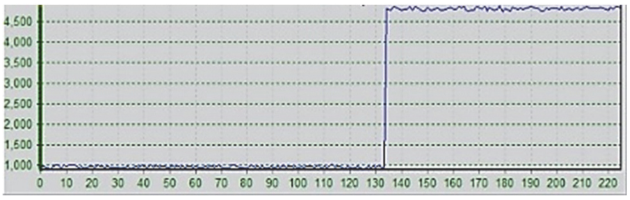


Figure 6 Laser power dynamic change experimental test curve

The time of high-speed MEMS ESVOA to attenuate 20 dB can be less than 200 ns (10%-90%), so the speed of attenuation can be 10^8 dB/s in theory. As to the usage of LTS, we test it at the frequency of 10kHz. If we change the 7 dB attenuation, the LTS can quickly finish the attenuation between 2 laser pulses, so the speed of attenuation is better than 7×10^4dB/s. The test result is shown as in Fig. 6.

3.2 High Precision Experimental Test of LTS

The stability of laser and the accuracy of MEMS ESVOA attenuation guarantee the high accuracy of simulated laser pulse power fitting the reality.

We test the accuracy of MEMS ESVOA attenuation at step of 1dB using the optical power meter. At the range of 40dB attenuation, the error is no more than 0.1 dB, and the linearity of MEMS ESVOA attenuation line is 0.1%. The test curve is shown in Fig. 7. Horizontal axis shows theoretical value, and vertical axis shows actual test value, while the unit is dB (relative energy). Although the attenuation range can be infinite in theory, we use two VOAs to get more than 80 dB in our experiment.

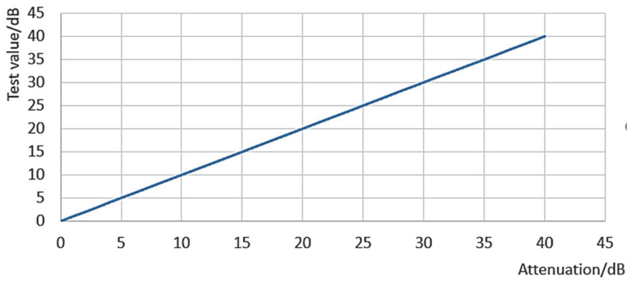


Figure 7 The test of high-precision attenuation

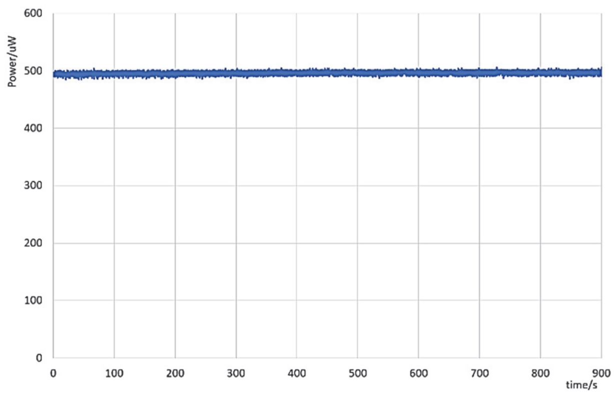


Figure 8 Energy stability test data

Auto temperature control loop and auto-power control of laser make the laser pulse energy very stable, meanwhile the MEMS ESVOA driver keeps the MEMS ESVOA attenuation stable too, so the laser echo pulse power is stable. The power instability of long time (more than 900 seconds) is better than 0.61%. The test curve is shown in Fig. 8.

4 CONCLUSION

In this paper, a new method of laser target simulator with low cost, miniaturization, high attenuation rate and high precision is discussed from the point of view of getting target echo laser. The experimental test of the prototype shows that the dynamic change rate of laser power is greater than 7×10^4 dB/s, the power precision is better than 0.1 dB and the laser power stability is better than 0.61%. The method overcomes many disadvantages of traditional methods and has been applied in the test of Lidar for atmosphere.

Because the MEMS ESVOA uses a reflector to obtain the attenuation of laser, it is easy to change the wavelength of laser by changing the coating with no regard to the mirror's material. In addition, cascaded MEMS VOA can attenuate the laser to very low power, even singe-photon scale in theory, so it may be a method of single-photon source. However, the precision calibration of MEMS VOA producing small laser signal should still be studied.

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