Defence Science Journal, Vol. 64, No. 1, January 2014, pp. 88-92, DOI:10.14429/dsj.64.4857

SHORT COMMUNICATION

A User Programmable Electro-optic Device for Testing Laser Seekers

Nakul Maini*, Akul Sabharwal, Kshitij Sareen, Anindita Singh, and Pradeep Kumar

Amity University, Noida, Uttar Pradesh-201 301, India

**E-mail: maini.nakul@gmail.com*

ABSTRACT

Laser-guided munitions are weapons of great importance in the present day warfare scenario because of their precision and efficacy. Both weapon specific and generic test systems are commercially available to perform functionality checks on laser guided munitions. None of the designs reported in literature addresses the issues of universality of test systems and their ability to evaluate the device-under-test in actual battlefield scenario. This paper presents the design of an electro-optic device that offers significant improvement over the features of both commercial test systems as well as the designs reported in recent literature. The proposed design enables generation of user programmable laser signatures in terms of pulse repetition frequency (PRF) code, PRF code resolution and laser power density that allows testing in dynamic conditions not possible with the test systems in the state-of-the-art. The concept is hardware implemented and used to evaluate performance of a typical laser seeker. The seeker is tested for PRF code compatibility, immunity to false PRF codes, sensitivity, field-of-view and performance in dynamic conditions. The test results are also presented.

Keywords: Field-of-view, functionality check, laser seeker, PRF code compatibility

1. INTRODUCTION

Successful use of modern guided munitions began in 1943 with the German Navy introduced the first acoustic-homing torpedo, the G7e/T4 Falke (Falcon). Although the T4 was only employed by three U-boats before being replaced by the G7es/T5 Zaunkönig (Wren), it reportedly sunk several merchant vessels. Subsequent to this, an American Mark-24 acoustic-homing torpedo released from a patrol aircraft sank the German submarine U-640. Four months after destruction of U-640 submarine, fifteen German Dornier-217 medium bombers attacked the Italian fleet with Fritz-X radio guided glide bombs[1].

Semi-active laser (SAL) guided weapons are widely used for the advantages such as high-precision, immunity to jamming, low cost, and so on[2-3]. Their efficiency has been established beyond the slightest doubt in several major wars in the last couple of decades[4-5]. Laser designators and seekers use a pulse coding system to ensure that a specific seeker and designator combination work in harmony. The designator and seeker pulse repetition codes use a truncated decimal system. This system uses the numerical digits 1 through 8 and the codes are directly correlated to a specific PRF. Coding allows simultaneous or nearly simultaneous attacks on multiple targets by a single aircraft, or flights of aircraft, dropping laser guided munitions set on different PRF codes. This concept may be employed when several high priority targets need to be expeditiously attacked and can be designated simultaneously by the supported unit(s)[6-7]. Though comprehensive test set-ups exist for characterization of seeker heads of laser guided munitions; there is always a requirement to develop portable electro-optic devices that can perform quick functionality checks on these weapons to ensure near 100% target hit probability[8].

2. LIMITATIONS OF COMMERCIAL AND REPORTED TEST SYSTEMS

The portable test systems offered by major international manufacturers including Lockheed Martin, Geotest Marvin Inc and others are either weapon specific or offer limited testing capability.

One such test system is mission readiness test set (MRTS) type TTU 594A/E from Lockheed Martin Corporation[9]. The test system is weapon specific and is designed to test Paveway-II series of laser guided munitions; cannot check the sensitivity of seeker head and does not test the seeker in realistic battlefield conditions as the test laser radiation doesn't overspill the laser seeker[10]. Another well known test system called laser source simulator type MT 1888/1888A from Geotest Marvin Inc is a field programmable device that can generate laser signatures of the target[11]. However, the device cannot be used to test the seeker for its full dynamic range. Some test system designs are reported in literature to overcome most of the shortcomings of the above mentioned systems[12-13]. The proposed design offers user programmability of PRF codes, power density and field-of-view.

3. DESIGN CONCEPT

Figure 1 shows the schematic of the proposed design concept of the electro-optic device. The design is configured around a high bandwidth semiconductor laser diode module

Received 17 July 2013, revised 11 November 2013, online published 23 January 2014

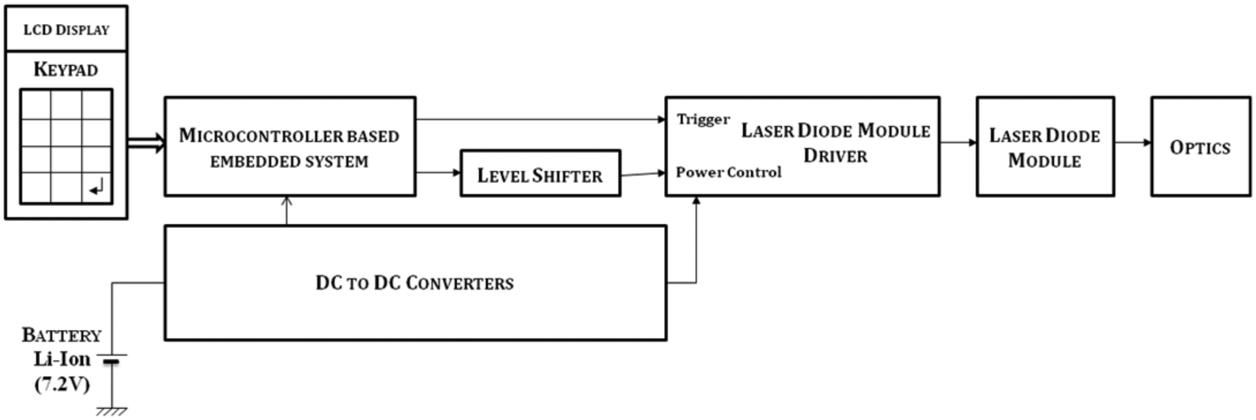

Figure 1. Schematic arrangement illustrating the design concept.

generating continuous wave (CW) power of 100 mW driven by a programmable laser diode driver circuit. High bandwidth of laser diode module allows generation of nano second wide laser pulses required to simulate battlefield laser target designator. The diode laser driver is in turn driven by a microcontroller based embedded circuit. The embedded circuit is interfaced with a suitable matrix key pad and an LCD display. Optics placed at the output of laser diode module is used to generate laser beam of desired shape and divergence. A rechargeable lithium-ion battery of 7.2 V/3.5 Ah feeds a DC-to-DC converter module that generates all the required regulated DC voltages for operation of different circuits.

Typical laser guided munitions delivery parameters include wavelength of 1064 nm, PRF of 10-20 pulses per second, pulse width in the range of 10-20 ns and pulse energy in the range of 50-120 mJ. The PRF code is usually specified with accuracy in the range of $\pm$ 1 – 5 µs in time interval. It is important that the test system generates laser radiation with these specifications and a variable power density as seen by laser seeker whiule in flight.

The laser power density as seen by the laser guided munitions seeker head cross-section depends upon a number of parameters including laser designator parameters, atmospheric parameters, target characteristics and deployment mode[14]. These parameters include the following.

- Peak transmitted power from the laser target designator, P_T (W)
- Power received by receiving aperture, P_R (W)
- Transmitted beam diameter, D_T (m)
- Transmitted beam width full angle, θ_B (rad)
- Laser target designator-to-target distance, R_T (m)
- Target-to-receiver distance, R_R (m)
- Sea level atmospheric attenuation coefficient, σ_W
- Fractional decrease in atmospheric attenuation coefficient as a function of height of laser target designator above sea level, α_{HT}
- Fractional decrease in atmospheric attenuation coefficient as a function of height of receiver above sea level, α_{HR}
- Target reflectivity, ρ
- Angle between transmitter line-of-sight and normal to the target, θ_T (rad)
- Angle between receiver line-of-sight and normal to the target, θ_R (rad)
- Angle between receiver line-of-sight and normal to receiver aperture, θ_A (rad)
- Projected spot area in a plane orthogonal to transmitter line-of-sight, A_N (m^2)
- Projected spot area in a plane orthogonal to receiver line-of-sight, A_M (m^2)
- Laser beam area at a given distance, A_B (m^2)
- Target surface area, A_T (m^2)
- Area of receiving aperture, A_R (m^2)

Laser power density can be computed from the generalized expression for received power as given by Eqn. 1. In both cases, for guidance ranges of 5 km and 250 m, the expected power density values can be computed by substituting typical values of various parameters in Eqn.1. These are approximately 5 and 2000 µW/cm^2 respectively for weapon-to-target distances of 4-5 km and 250-300 m[10].

$$P_R = \left[\frac{4\rho P_T A_R A_T \cos\theta_T \cos\theta_R \cos\theta_A e^{-\sigma_W(\alpha_{HT} R_T + \alpha_{HR} R_R)}}{\pi^2 (D_T + \theta_B R_T)^2 R_R{}^2} \right] \tag{1}$$

With reference to the schematic arrangement of Fig.1, the desired PRF code as entered through the keypad is generated by the microcontroller based embedded circuit and the code is displayed on the LCD. The Laser driver block is basically a DC voltage programmable constant current source that provides the required current drive to the Laser diode module. The DC control voltage is also generated by the microcontroller by using on-chip counter and D/A converter. The D/A converter output is level translated to meet the requirements of control voltage for the laser diode driver circuit. The embedded circuit design allows the user to either select a discrete single value of control voltage to get a certain specific power density in 100 µW/cm^2 - 1000 µW/cm^2 range or a variable power density in the same range in time duration in seconds defined by the user through the key pad. The pulse repetition frequency of the radiation from the laser module is decided according to the PRF code entered by the user. The optics produces a laser spot diameter of 70 mm at the device-to-seeker under test distance of 1.0 m. Maximum laser power of 100 mW and a laser spot diameter of 70 mm produce a maximum power density of 2.0 mW/cm^2 allowing for the transmission losses of about 30 per cent in the output optics. Discrete power density values down to 1.0 μW/cm^2 or lower can be obtained by either increasing test device-to-seeker distance or using appropriate neutral density filter at the exit of the device.

Major specifications of the device include output centre wavelength of 1064 $\pm$ 2 nm with $\cong$ 0.8 nm line width (Fig.2), selectable pulse width of 10 and 20 ns, selectable pulse repetition frequency (PRF) in the range of 5-50Hz with a time interval resolution of $\pm$ 1 μs and selectable power density levels of 100 μW/cm^2 and 1000 μW/cm^2. The spectral profile of the laser module output was plotted at a constant drive current of 80 mA and laser diode operating temperature of 25 °C. It may be mentioned here that the laser diode module is operated by a constant current driver source and that the constant operating temperature is ensured by an in-built thermoelectric controller. Minimum and maximum power density values of 10-100 μW/cm^2 and 1-10 μW/cm^2 can also be produced by using neutral density filters of optical density 1.0 and 2.0 respectively. These values can also be produced by increasing the test distance to 3.3 m and 10 m respectively. The device produces a laser beam of 70 mm diameter at the cross-section of seeker under test when kept at a distance of 1.0 m from the test device.

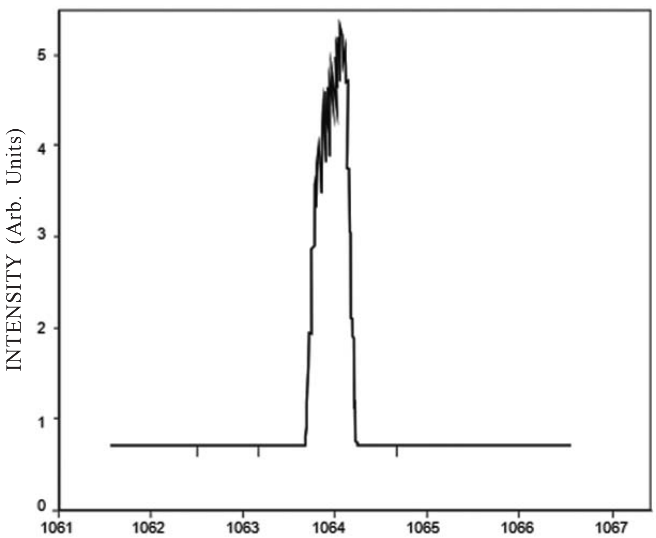

Figure 2. Spectral profile of laser output.

4. HARDWARE DEVELOPMENT

The device is configured around the 100 MHz bandwidth continuous wave laser diode module and the associated drive and control electronics. The pulsed waveform needed for triggering the laser diode module is generated in the embedded subsystem configured around microcontroller. The microcontroller is interfaced with 3 x 4 matrix keypad and 8 x 2 LCD display. The time period of the generated waveform is entered by the user from the keypad, which is subsequently displayed on the LCD display. The desired pulse width of 10 ns – 20 ns is generated by the Monoshot circuit.

The laser diode chosen for the design has its output wavelength centered on 1064 nm. It has a modulation bandwidth of 100 MHz, output power of 100 mW and FWHM of 0.5 nm. The module also has an in-built TEC and the associated control circuit to stabilize the diode temperature and hence the wavelength. The device is battery operated and employs a 7.2-V/3.5-AH rechargeable Li-Ion battery having built in protection against deep discharge.

The laser beam at the exit of the laser module has a diameter of 3.0 mm and a full angle divergence of 1.0 mrad. The laser beam is made divergent to an angle of approximately 4° using a negative lens to get an output beam diameter of 70 mm @ 1.0 m distance. A borosilicate optical window is used at the output for protection. A modular, portable, lightweight and easy-to-use mechanical package was designed for the device. Figure 3 shows the photograph of the fabricated prototype.

Figure 3. Photograph of electro-optic device prototype.

5. TEST RESULTS

The device prototype was used to evaluate the performance of a laser seeker unit (Make: LIZARD Seeker from M/s Elbit Systems, Israel). Following tests were performed on the seeker unit.

5.1 PRF Code Compatibility Test

Fig.4 shows the test set-up. Ten different PRF codes were programmed into the laser seeker and the electro-optic device, one at a time with 100 μW/cm^2 power density setting. The lock-on condition was checked on the G.U.I. that was developed in accordance to the seeker. The test was repeated with 1000 μW/cm^2 power density setting. Similar results were obtained. The results are summarised in Tables 1.

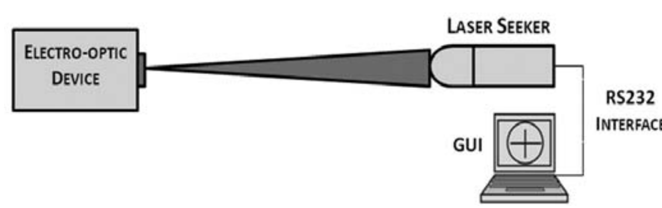

Figure 4. Test set-up.

5.2 False Code Rejection Test

Different PRF codes were programmed in the laser seeker and the electro-optic device. The seeker remained in the acquisition mode. Ten different settings were used. In each of the settings, the seeker continued to remain in acquisition mode indicating an out-of-lock condition. Test results are summarized in Table 2.

Table 1. PRF code compatibility tests (Power density setting at 100 μW/cm^2 and 1000 μW/cm^2)

PRF code setting in electro-optic device (ms)	PRF code setting in laser seeker unit (ms)	Seeker unit lock-on status mode
50.000	50.000	Tracking mode
80.000	80.000	Tracking mode
100.000	100.000	Tracking mode
105.042	105.042	Tracking mode
105.984	105.984	Tracking mode
106.044	106.044	Tracking mode
106.188	106.188	Tracking mode
106.398	106.398	Tracking mode
106.598	106.598	Tracking mode
107.008	107.008	Tracking mode

Table 2. False code rejection test (Power density setting = 100 μW/cm^2)

PRF code setting in electro-optic device (ms)	PRF code setting in laser seeker unit (ms)	Seeker unit lock-on status mode
50.000	80.000	Acquisition mode
80.000	50.000	Acquisition mode
100.000	105.042	Acquisition mode
105.042	100.000	Acquisition mode
106.188	105.984	Acquisition mode
105.984	106.188	Acquisition mode
106.398	105.188	Acquisition mode
106.598	106.398	Acquisition mode
106.610	107.008	Acquisition mode
107.008	105.984	Acquisition mode

5.3 PRF Code Resolution Test

The test was performed by programming same PRF code in the electro-optic device and seeker unit and response of seeker monitored. The PRF code was incremented in steps of 1.0 µs and the seeker response recorded for each incremental setting. For time interval difference of >5.0 µs, seeker was observed to switch from tracking to acquisition mode indicating out-of-lock condition. The results are summarized in Table 3.

5.4 Field-of-View Test

The field-of-view was measured by giving angular movement to the seeker head in both directions around the centrally aligned position and recording its response. The test was performed at 100 µW/cm^2 and 1000 µW/cm^2 power density settings. The fields-of-view in the two cases were measured to be ± 12.5^o and ± 10°.

5.5 Sensitivity Test

Sensitivity was measured by gradually reducing the power density of laser radiation falling on the seeker head with the help of appropriate neutral density filters of required optical density and adjustment of seeker head-to-test device distance. The seeker was observed to go out of lock with a filter of optical density 2.0 and device-to-seeker distance of >2.0 m thereby indicating a 0.25 µW/cm^2 figure for sensitivity.

Table 3. PRF code resolution test

PRF code setting in electro-optic device (ms)	PRF code setting in laser seeker unit (ms)	Seeker unit lock-on status mode
100.000	100.000	Tracking mode
100.001	100.000	Tracking mode
100.002	100.000	Tracking mode
100.003	100.000	Tracking mode
100.004	100.000	Tracking mode
100.005	100.000	Tracking mode
100.006	105.188	Acquisition mode
100.007	100.000	Acquisition mode
100.008	107.008	Acquisition mode
100.009	100.000	Acquisition mode

5.6 Seeker Response to Changing Power Density

The electro-optic device was programmed to produce changing power density of 100 µW/cm^2 - 1000 µW/cm^2, 10 µW/cm^2 – 100 µW/cm^2 and 1 µW/cm^2 – 10 µW/cm^2 in three steps in time duration of 20 seconds, typical of the flight duration of a laser guided munitions in the terminal guidance range. Seeker response was monitored. The seeker was observed to stay in the locked state.

6. DISCUSSION AND CONCLUSION

The paper describes design concept and prototype hardware of a portable electro-optic device to test seeker heads of laser guided munitions. The proposed design offers universality, user programmability, ability to check all important parameters and portability to allow on-platform testing as against weapon specificity, fixed output, ability to check only one or two parameters and bench top testing of existing commercial systems and reported designs. These features are not available in the existing test systems, which mainly test the PRF code compatibility of the seekers.

REFERENCES

1. Watts, Barry D. Six decades of guided munitions and battle networks: progress and prospects. Center for Strategic and Budgetary Assessments, March 2007.
2. Chambers II, J.W. Precision guided munitions. The Oxford Companion to American Military History, 2000.
3. Higgins, D.J. Precision guided munitions in an urban environment. Air Command and Staff College, Air University, April 2006.
4. Martin, R.G. & Robinson, E.L. Automated laser seeker performance evaluation system (ALSPES). Automated Testing of Electro-optical Systems, *SPIE 0941*, 04 August, 1988, pp 73-77.
5. Roberts, D. & Capezznto, R. AGM-114 Hellfire missile system and FLIR/LASER test and integration on the H-60

aircraft. *In* the Proceedings IEEE Aerospace Conference, 1999, **3**, pp 63-72.

6. Murphy, Matthew G; Blake, Jesse H. & Garcia, Carlos. Optically coupled communication interface. United States patent 8344302, Jan 2013.
7. Military Analysis Network. Laser Guided Bombs, *www.fas.org/man/dod-101/sys/smart/lgb.htm*, Feb 2000.
8. Chrzanowski, K. Testing of military optoelectronic systems. *Optoelectronics Review*, 2001, **9**(4), 377.
9. Lockheed Martin Corporation. TTU 594 A/E Mission Readiness Test Set, *07ARC04*, *www.lockheedmartin.com*, 2007.
10. Maini A. K. & Verma A. L. Pre-flight functionality check to enhance mission efficacy of precision guided munitions. *Def. Sci. J.*, 2009, **59**(5), 459-465.
11. Geotest Marvin Test Systems Inc. MT-1888 series Laser Source Simulator, *www.geotestinc.com*, 2013.
12. Maini, A.K. & Agrawal, Varsha. Portable electro-optic device for performing serviceability checks on laser-guided munitions. *J. battlefield Technol.*, 2009, **12**(2), 1-4.
13. Maini, A.K.; Verma, A.L. & Agrawal, V. New electro-optic simulator design concepts for serviceability checks of laser seekers and laser warning sensors. *J. Battlefield Technol.*, 2010, **13**(2), 29-35.
14. Strohm, Luke S. A terminal guidance model for smart projectiles employing a semi-active laser seeker. Army Research Laboratory, Technical Report No. ARL-TR-5654, August 2011.

CONTRIBUTORS

Mr Nakul Maini is an BTech (Electronics and Communication) from Amity University, Noida. He has authored and co-authored 10 publications in national and international magazines and peer reviewed journals. He is currently a Technical Editor Trainee in Wiley Publications.

Mr Akul Sabharwal is an BTech (Electronics and Communication) from Amity University, Noida. He has co-authored two publications. He is currently a Design Engineer in Simmtronics Semiconductors Ltd.

Mr Kshitij Sareen is an BTech (Electronics and Communication) from Amity University, Noida. He is currently preparing for admission to the post graduate program.

Ms Anindita Singh is an BTech (Electronics and Communication) from Amity University, Noida. She is currently a Manager Public Relations in Universal Sompo General Insurance Company, Lucknow.

Dr Pradeep Kumar has done his MSc from C.C.S. University Meerut, and the PhD from H. N. B. Garhwal University Srinagar Garhwal. He is currently a faculty in the Department of Electronics & Communication Engineering, ASET, Amity University, Noida.