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Testing and Evaluation of High Energy Portable Laser Source used as a Target Designator along with a Laser Seeker

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ABSTRACT

Precision guided munitions are often driven with the help of a special kind of laser beam, pointing onto the target of interest which can be a ground based stationary target or a moving one. The laser source which is popularly known as target designator is a key element in this and plays a vital role in performing any laser guided bombings. In this paper a testing methodology and evaluation technique is described for such a portable high energy laser source. The parameters of the designator are tested in laboratory environment as well as verified in field conditions. The measured and tested parameters are laser source energy, pulse repetition frequency, laser wavelength accuracy and pulse width. A laser guided bomb seeker is also used to test with and verify different designator parameters specially the pulse repetition frequency (PRF) in field conditions. The PRF is generally set in the seeker manually and the designators are fired onto a target for different PRFs and energy levels. If the PRF of the seeker matches with that of the designator then it locks onto the target and if different it does not. In this experiment one more designator is also fired onto a different target within the field of view of the seeker with the same parameters except the energy level. The seeker changes its position to the target having higher energy density provided pulses are within its detection window.

Keywords: Circular error probability; High energy portable laser source; Full width half maximum; Pulse repetition frequency; Inertial navigation system; Global positioning system; Laser guided bomb

NOMENCLATURE

E_d	Laser energy of designator (mJ)
P_d	Peak power of a designator pulse (MW)
P_t	Peak power of a pulse on target (MW)
P_s	Peak power of a pulse on seeker end (W)
R_d	Distance of target from designator (km)
R_s	Distance of seeker from target (km)
D	Seeker receiver aperture diameter (mm)
A	Seeker receiver cross section (m^2)
μ	Atmospheric attenuation per km
V	Environmental visibility (km)
Λ	Laser wavelength (nm)
θ	Angle of target position w.r.t. designator (deg)
β	Angle of target position w.r.t. seeker (deg)

1. INTRODUCTION

With the simultaneous advent of both the laser technologies and data processing capabilities the complete concept of the weapon delivery system got improved. It's not only the technique but also the shape and size of a bomb also got changed drastically. Laserbeam guidance enabled the bombs just become more and more precise in hitting a target or with improved CEP which thereby reducing the amount of ammunitions required for a specific damage of any target. Advanced data processing technology enabled the bomb to be much smarter than earlier dumb kind of versions[1,2]. A semi active guidance system of a laser guided bomb (LGB) consist of mainly a laser sensor and processing unit, canards for the mechanical guidance and a wing section towards the tail of the bomb. The laser sensor and processing unit is popularly known as laser seeker. The front end is the optical receiver to gather laser scattered radiations from the illuminated target and the required photo detector assembly with data conditioning modules. Next portion of the bomb is the controlling guidance canards which are attached to the warhead part of the bomb. The job of these canards is to provide steering commands of the LGB. The tail portion consists of the wings to provide lift to the LGB. Once the LGB is released from the launch vehicle it goes through mainly three phases - Ballistic phase, transition phase and finally Terminal phase. Ballistic phase is a very critical phase since the way the LGB is being released from the aircraft determines to some extent the manoeuverability in the last terminal phase also. So, the velocity vector in this initial phase is an important parameter. In the transition phase the acquisition of the laser illuminated target is started. Once any laser radiation is detected by the seeker it goes into the terminal actions. In the final terminal phase the laser radiation coming from the target reflections starts centering the seeker and the canards are commanded to align the LGB towards the target[1-3].

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This paper is mainly focused on to the testing and measurement of different parameters of two similar laser target designators used in laboratory and field conditions. The designators are tested along with a laser seeker for different energy levels and pulse repetition frequencies in field conditions. The two designators are fired onto two targets within the field of view of the seeker from different locations as shown in Fig. 1.

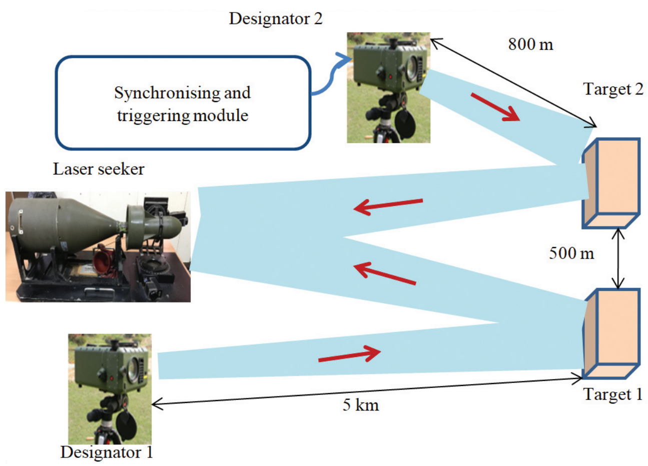

Figure 1. Target designation and seeker study.

2. TESTING AND EVALUATION OF HIGH ENERGY PORTABLE LASER SOURCE

The Laser beam source used in battlefield for LGB delivery is basically a Q-switched solid state high energy pulsed laser packaged with portability. This kind of laser source is popularly known as laser target designators used to illuminate an aim point target. The laser designator is fired at a particular frequency called pulse repetition frequency (PRF) and at a suitable energy level depending on the target distance and weather conditions. The important parameters that are being programmed in the laser primarily are - Laser Energy, PRF, and ON Time etc. The PRF is an important parameter because this is basically the code being programmed in the Seeker data base to identify the laser radiation scattered back from a designated target. This PRF Code determines whether the laser is a friendly laser or a hostile one. If the PRF set in the LGB Seeker matches with that of the Designator laser radiation the acquisition of the target is started.

The major specifications[2, 3] of the laser being used are as follows –

Laser wavelength	: 1064 nm ± 1 nm
Laser pulse width	: 20 ns
Pulse repetition frequency	: 5 to 20 Hz
PRF accuracy	: ± 5 μsec
Maximum energy level	: 100 mJ
Beam divergence	: 0.3 mrad

2.1 Laser Source Wavelength and Accuracy Measurement

The wavelength and its accuracy of the laser are being tested using a spectrometer of and the result with accuracy got as 1064 ± 0.3 nm.

Spectrometer Make: Avantes

The green line in the plot of Fig. 2 shows the peak wavelength of the laser pulse which at 1064.244 nm. Multiple readings are observed and the peak wavelength is obtained within 1064 ± 1 nm.

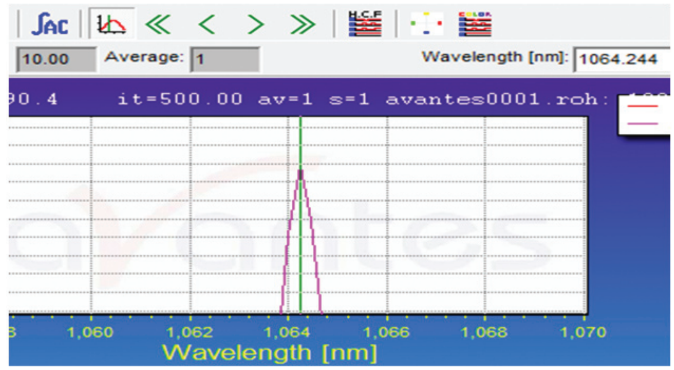

Figure 2. Laser wavelength measured by spectrometer.

2.2 Laser Pulse Width Measurement

The laser pulse width is measured with a photodiode module and oscilloscope. The designator is fired onto a metallic plate as shown in Fig. 3 and the scattered laser beam is sensed by a photodetector module. The photodetector output is connected to a standard oscilloscope to measure the laser pulse width of the designator. The details of the equipments used are given as follows:

Photodetector : Make Alphalas, (Model No. UPD-300-UD)

Oscilloscope : Make Tektronix, (Model No. MSO4104B)

The pulse width of the photodiode output is measured at FWHM and found to be in the range of 20 ns as shown in the Fig. 4. Pulse width and wavelength is required in here is to design the synchronising and triggering controller module for the 2nd designator. The seeker is also designed for this wavelength.

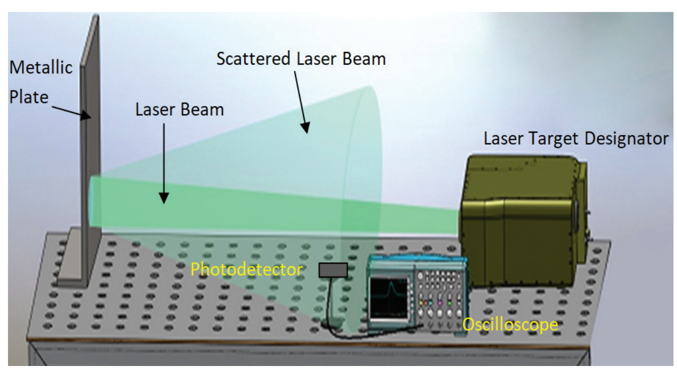

Figure 3. Setup for measuring laser pulse width.

2.3 Output Energy Measurement

The details of the equipments used for the measurement of the output energy of the designator is as follows –

Energy Meter : Make OPHIR (Model No. VEGA 7Z01560)

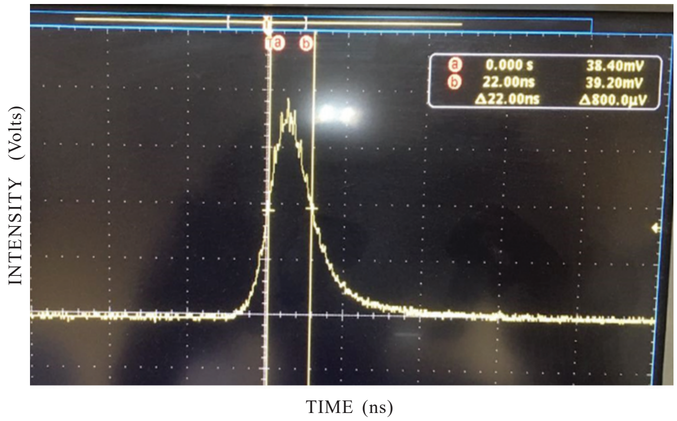

Figure 4 Photodiode output pulse.

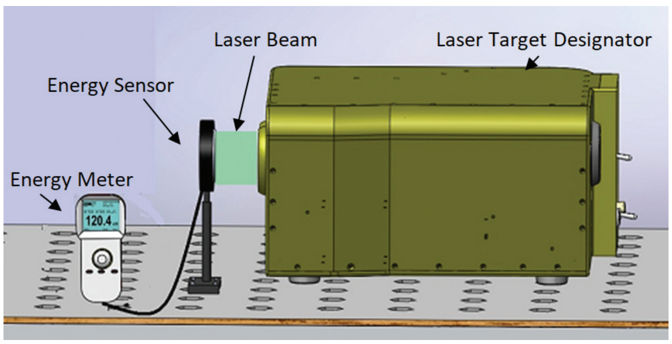

Figure 5. Setup for laser output energy measurement.

Energy Sensor : Make OPHIR
(Model No. PE50SHV2)

The set up for laser output energy measurement is as shown in the Fig. 5.

The maximum available energy per pulse is measured to be around 100 mJ. The locking of Elbit seeker was also checked at this energy level by placing the seeker at a distance of 5 km as shown in Fig. 1 earlier.

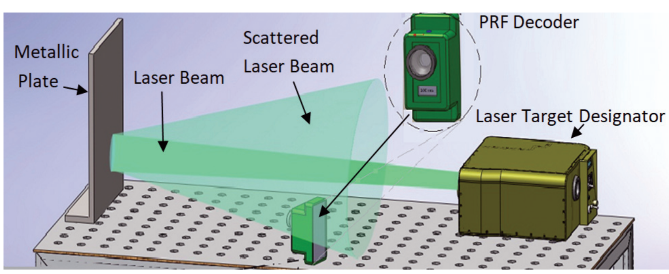

Figure 6. Setup for PRF code measurement of laser.

2.4 Laser Pulse Repetition Frequency Measurement

Designator is fired at different laser pulse repetition frequency (PRF) and measured with the help of a PRF decoder available at LASTEC and verified the pulse repetition frequency using a standard frequency counter with the following make/model. The PRF accuracy obtained of this laser source is around ± 5 µs. The set up is as shown in Fig. 6.

Frequency counter: Agilent 53220A 350 MHz universal frequency counter/timer.

2.5 Laser Beam Divergence Measurement

The laser beam divergence is measured using a beam profiler of ophir and silicon CCD camera of Spiricon make set up and the measurement is carried out at the laser source manufacturer site. The beam profiler camera is placed on the focal point of the mirror which is alligned with the laser beam. Divergence measured for 80 per cent of beam energy is found to be around 0.25 mrad which is less than 0.3 mrad as per the specifications mentioned. So, idealy for a 0.25 mrad divergence the spot size at 5 km distance should be around 1.25 m. Practically the spot size noted at a distance os 5 km is around 1.5 m to 2 m wide with scintillation due to atmospheric disturbances.

3. TESTING WITH ACTUAL LASER SEEKER IN FIELD

The laser designator has been tested with a standard laser seeker in field condition as depicted in Fig. 1 in the introduction above. The testing was carried out with the following arrangements (Fig. 7 and Fig. 1 in detail).

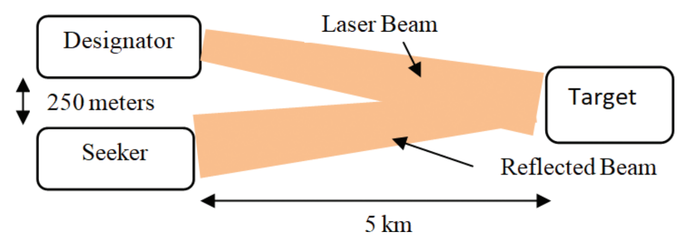

Figure 7. Setup for field testing of designator with seeker.

Equipments and set up used are

Laser Seeker M/s Elbit Systems
Designator M/s Bharat Electronics Ltd.
Target Concrete Structure

The testing was carried out in different environmental visibility conditions and the seeker was able to lock onto the laser backscattered signals from the concrete structure being designated from 5 km away. The laser spot size onto the target is taken nearly 2 m. The laser power level in the seeker end calculated as follows:

Estimation of received power level at seeker end

Condition 1

Environmental visibility is around 10 km and the atmospheric attenuation for 1064 nm wavelength laser is calculated as follows:

According to Kruse model[5] -

$$\text{Attenuation Coefficient}^5,\ \mu = \frac{3.912}{V}\left(\frac{1064}{550}\right)^{-q} \quad (1)$$

For a visibility range[5] 6 to 50 km $q = 1.3$

So, for $V = 10$ km, $\mu = 0.166$ per km

Peak power per pulse at target[6-7]

$$P_t = P_d e^{-\mu R_t} \quad (2)$$

If the designator is fired at its maximum available energy level of 100 mJ energy then

Peak power per pulse is $P_d = 5$ MW

For a range of 5 km, the peak power per pulse at target would be

P_t = 2 MW (3)

The laser pulse then gets reflected and scattered from the target structure throughout a hemispherical area towards the seeker side. It is considered a hemispherical area because the seeker and designator 1 are almost collocated or a very small distance apart in comparison to the target distance which is 5 km. Also the target 1 is a concrete structure and the laser falls onto a wall of it.

The power level received by the seeker receiver is calculated as follows –

Seeker receiver aperture diameter D = 25.4 mm

So, cross sectional area $A = \frac{\pi D^2}{4}$

$$A = 506.7 \times 10^{-6}\, m^2 \quad (4)$$

Power received by seeker aperture is given[6-7] by –

$$P_s = \frac{A.P_t.\cos\theta.r.e^{-\mu R_s}}{\pi R_s^{\,2}} \quad (5)$$

For, θ = 10° and target reflectivity[6] r = 25 per cent the peak power received by the seeker is calculated as –

$P_s = 1.385\mu W$ approx. (6)

The seeker is able to lock onto the target 1 with this power level scattered from the target. This is verified by seeing the status of the seeker whether it is in the acquisition mode or in track mode. The seeker is observed to stay in the track mode. Also to verify that the locking is happening to the actual target, the seeker is fixed to an angular motorized pan and tilt arrangement. Once the line of sight (LoS) of the target w.r.t. the seeker is established the locking of the seeker with the actual target is being verified in real time.

Condition 2

Environmental visibility is low and around 2 to 3 km –

In such a foggy situation the atmospheric attenuation for 1064 nm is given by –

Attenuation Coefficient, μ = 0.921 per km

from Eqn. (1)]

So, for a range of 5 km, the power level at target would be

P_t = 50 KW (Peak power per pulse) (7)

from Eqn. (2)

The peak power received by the seeker aperture is –

P_s = 0.794 nW Approx (8)

from Eqn. (5)

In this situation where the visibility is very low and less than 2 km it is difficult for the seeker to lock onto the target. The seeker in a dense foggy situation is not able to sustain in track mode.

Condition 3

A similar designator is also aligned with another target (target 2) at 500 m away from the target 1 as shown in Fig. 1 within the field of view of the seeker. Initially the designator 1 is fired onto target 1 at a certain PRF (same as set in the seeker). The seeker locks onto the target 1 as per the condition 1 described above. The synchronising module detects the designator 1 pulses and triggers the designator 2 which is aimed at target 2. This designator starts firing onto the target 2 at a nearer distance than that of the first designator (800 m away) and fired at the same energy level as that of the designator 1. If the PRF values set in the seeker and the designators are same the seeker changed its locking position onto the target 2 as the seeker in this case is exposed to higher energy levels from the new target. One more vital parameter to be strictly controlled by the synchronising module is the time synchronisation between both the designators so that their pulses come within the seeker detection window which is generally in μs level. This experiment is carried out for different PRF values for both same as set in the seeker as well as different than that set in the seeker. In every case if PRF codes are matched then the seeker locks onto the target direction having higher energy densities and same PRF code.

4. REMOTE LASER DATA ANALYSIS IN FIELD CONDITIONS

Important parameters viz. laser pulse repetition frequency (PRF) is also often needed to be monitored in real time if any changes happen in real time while laser is fired. Actually the designator no. 2 is synchronised with and triggered by the designator no. 1 with the help of the synchronising module as shown in Fig. 1. The laser output pulses from the designator no. 2 are converted into electrical signals using a photodetector module and transmitted through a long distance wired link to a safer location which may be a few kilometres away from the target aim point of the LGB drop under testing.

A kind of portable field deployable signal repeater is designed and developed based on RS-485 protocol which can cater for a data link of more than a kilometre of distance. The set up is used as shown in Fig. 8.

This RS-485 repeater device is designed for field applications which are powered by a rechargeable battery bank and a low battery indicator module inside. The internal RS-485 transceiver module can take differential inputs and amplifies to a level suitable of transmission again up to more than a kilometre distance. The input to this repeater is basically the differential

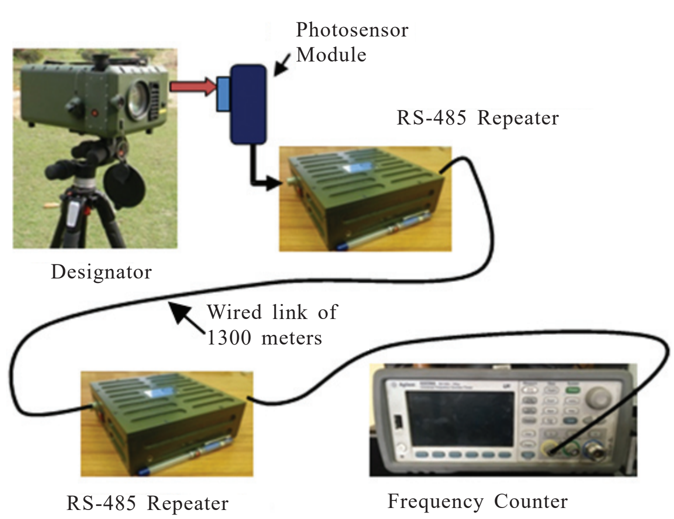

Figure 8. Field setup for measuring laser PRF remotely.

pulses obtained through a laser pulse detector detecting laser triggered at a particular pulse repetition frequency. The pulses are transmitted through this repeater module and measured the PRF using a pulse counter which can display the PRF value in real time. The PRF of the laser being measured is verified in terms of pulse repetition time (PRT) using a standard frequency counter as discussed in the earlier section. Such two RS-485 repeaters can provide a range of more than 02 km in field testing conditions.

5. SAFETY MEASURES

The laser source is a class-4 lasers, so utmost precautions is taken while operating within the lab as well as in field conditions. In laboratory it is operated in a closed room and all users used protective goggles with optical density of OD 7 for 1064 nm wavelength as per ANSI Z136 standard. The reflected laser strength is estimated as below –

Considering visibility V = 10 km, atmospheric attenuation

$$\mu = 0.166 \text{ per km} \tag{9}$$

Testing within lab is carried out for around 5 m separation from the designator and a reflecting metal plate. For a condition as follows –

Goggles efficiency – Optical density (*OD)* = 7

Goggles cross section a diameter (*d)* = 50 mm

Reflector plate reflectivity[6] (*r)* = 50 per cent

Distance between designator and reflector (*R)* = 5 m

Power received through goggles is given by –

$$P_s = \frac{A.OD.P_t.\cos\theta.r.e^{-\mu R}}{\pi R^2} \quad \text{from Eqn. (5)}$$

It comes around 7.5 μW peak power per pulse (20 ns pulse width) behind the goggles and so, it's within the human eye's permissible limit (1 μJ/cm^2 at 20 Hz for 60 s) as far as safety is concerned. More over although goggles are used, one should not look into the exit aperture of the laser transmitter directly.

6. CONCLUSIONS

LASTEC has been engaged in developing laser warning sensor (LWS) and laser countermeasure systems for defense applications. For testing the sensors and countermeasure systems the laser source plays an important role. The efficacies of LWS and countermeasure systems directly or indirectly depend upon the laser sources being used. The laser source parameters are tested and measured within laboratory with the procedures discussed here and verified with a laser seeker during field testing. For field conditions laser data is transmitted through the RS-485 Repeater module for real time monitoring during field testing. Measurement and matching of all the designator parameters as explained here is necessary for the LGB laser seeker to be able to recognise and lock onto the two designators. From the experiment it has been observed that if the laser parameters of the designator no. 2 are same as that of the designator no. 1 and set values in the seeker except the energy level (Energy density from target 2 is greater than Energy density from target 1) the LGB laser seeker has locked onto the designator no. 2 once it is triggered. After several experiments it has been seen that LGB laser seeker can be quite vulnerable to active laser based counter measure techniques. The regular testing of all the vital parameters presented in this paper is necessary for designing battlefield laser detection and countermeasure systems against such laser guided munitions.

REFERENCES

1. Maini, A.K. - Battlefield lasers and opto-electronics systems. *Def. Sci. J.*, 2010, **60**(2), 189-196, doi: 10.14429/dsj.60. 339
2. 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. doi: 10.14429/dsj.59.1547
3. Maini Nakul, Sabharwal Akul, Sareen Kshitij, Singh Anindita and Kumar Pradeep - A user programmable electro-optic device for testing laser seekers. *Def. Sci. J.*, 2014, **64**(1), 88-92. doi: 10.14429/dsj.64.4857
4. Fourie, J.P. & Yavin, Y. The guidance accuracy of a projectile using a wind stabilized seeker. Laboratory for Decision and Control, Department of Electrical and Electronics Engineering, University of Pretoria, Pretoria 0002, South Africa. *Computers Math. Applic*., 1993, **25**(3), 27-36.
5. Naboulsi, Al; Sizun, M.H. & Fornel, de F. Propagation of optical and infrared waves in the atmosphere. France Telecom, 6, Avenue des usines, BP382-90007 BELFORT Cedex, France, 2005.
6. Sabatini, Capt. R. tactical laser systems performance analysis in various weather conditions. Italian Air Force Research and Flight Test Division (DASRS), Pomezia 00040 (Rome), Italy, March 1998, TO-MP-001: 29-1 to 29-13.
7. Srinivasan, R.; Revathy, A.P.; Rao, GNVS Kasi V. & Solanki R.S. Optoelectronics system design for defence application. *In* ICOP-2009, International Conference on Optics and Photonics, Chandigarh, India, 31st October – 1st November 2009.

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Mr Tutul Gogoi obtained his graduation in Instrumentation Engineering from Assam Engineering College, Guwahati University, Assam in 2002. He is working as a Scientist at DRDO-Laser Science and Technology Centre, Delhi, India. He has vast experience in the field of target acquisition sensor technologies for directed energy systems, laser based systems in battlefield applications and laser threat detection and counter measures for the protection of high value assets against laser guided munitions.
In the current study, he is the key designer and responsible for the execution of the complete testing and evaluation of the systems being described in the article.

Ms Rajni Kumar did her Diploma in Electronics and Communications from Board of Technical Education, Delhi. She is working as a Technical Officer at DRDO-Laser Science and Technology Centre, Delhi, India. She has experience in the development of laser based systems for electro optic counter measures applications, sensors for electro optically guided

precision strike munitions, laser threat detection and counter measure system developments.
She has contributed in performing all the experiments being carried out.

Mr Joshua Anand Gladwin, is an Engineering Graduate from MITS Gwalior and MBA (IB) from IIFT New Delhi. His area of Interest is high speed imaging techniques for capturing ballistic events. Presently he is working with laser threat detection and counter measures where his area of work is developing diffuse reflectance target for counter measure, mechanical hardware realisation, getting system environmental qualified and comprehensive field trials along with users.
In this paper his contribution is developing schematics for different experimental set ups and developing Pan and Tilt arrangement for acquiring data through the laser seeker.

Mr Vivek Goyal is an Engineering Graduate from the prestigious Institution of Electronics & Telecommunication Engineers (IETE) India. Currently he is working as a Technical Officer at DRDO-Laser Science and Technology Centre, Delhi, India. He has experience in the development of laser systems for electro optic counter measure applications. He has also worked in sensor development for electro optically guided precision strike munitions and in laser threat detection and counter measures for the protection of high value assets.
He has contributed in different experiments for the work presented in this paper.