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Advanced Test System for Comprehensive Characterization of Laser Seekers in the Presence of Countermeasures

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Abstract Precision guided munitions play a pivotal role in battlefield success by providing commanders with highly improved weapon accuracy. Laser guided bombs are widely exploited precision guided munitions in the contemporary battlefield scenario. These sophisticated weapons are of great tactical importance and also have huge price tags attached to them. Various countermeasures have evolved to deceive them from their intended target. This makes it important that their effectiveness is guaranteed 100 percent by validating operational parameters in realistic operational conditions including the effects of countermeasures designed to defeat their intended objective. This paper presents the design of an advance test system that can be used for comprehensive testing of laser seekers including its response to various types of decoying techniques. The approach is to use lasers having the same wavelength, pulse width and PRF as that of laser designators and countermeasure lasers simulating the same power densities as seen by the laser seekers. The hardware is configured around two semiconductor diode lasers having output wavelengths of 1064nm and PIC microcontroller based embedded system to drive these lasers. The laser seeker head was extensively tested using this advanced test system. The test results are presented in the paper.

Keywords: *laser seek test system, semiconductor diode laser, laser guided munitions, decoy laser, laser countermeasures, laser designator, laser seeker*

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1. Introduction

In a laser guided bomb delivery operation, a high peak power pulsed solid state laser called Laser Target Designator irradiates the intended target with laser radiation. Laser radiation scattered from the target towards the guided bomb is detected by the seeker head in the bomb. The seeker head uses a position sensing device to determine information on the angular error, which in turn is used to generate command signals needed to guide the bomb to the source of scatter i.e. the target [1, 2]. Figure 1 illustrates the laser guided bomb delivery concept for a ground based laser target designator and aerially delivered munitions. In the other common delivery modes, the target designator and bomb are both airborne on the same platform; target designator and bomb are both airborne but on different platforms; and both target designator and munitions are land based. In all cases, before the munitions locks on to the target; it makes sure that the laser radiation is the intended one. To achieve this, the target designator and the laser guided munitions use the same pulse repetition frequency (PRF) code, which forms the basis of identification of intended target [3].

Due to the large scale proliferation of laser guided munitions, different types of countermeasures are being deployed to protect the target from laser assisted attack [4]. A common countermeasure involves detecting the laser radiation illuminating the asset to be protected, computing its direction of arrival and then creating a laser absorbing smoke screen to misguide the incoming munitions. In this case the decoy laser should only have the same PRF as the designator radiation. There is no need to generate time synchronization of the decoy signal with respect to the designator signal [5]. As a result of this the guidance system of laser guided munition goes out of lock, thereby drastically reducing its probability of hitting the target. Active laser jamming techniques have also been in use and are described in literature [6]. An emerging countermeasures system is based on the principle of detecting and deciphering laser threat from laser target designator and then using another laser to illuminate a dummy target placed in vicinity of the actual target with laser radiation of same characteristic parameters. The decoy laser radiation may be edge-matched, Advanced Time-Triggered or Delayed Time-Triggered to force the munitions to the dummy target rather than the real target. The seeker head of the laser guided munitions sees two spots and locks to the brighter one which is the last pulse of the two.

A number of international manufacturers offer test systems that can be used to perform serviceability check on laser guided munitions. These systems employ PRF compatibility check as the basis for declaring the weapon serviceable. Mission Readiness Test System (MRTS) from M/s Lockheed Martin Corporation, Laser Source Simulator type MT 1888A from M/s Geotest-Marvin Inc. and Line Level Test Equipment (LLTE) for Griffin kit are some examples. Portable test systems that can perform serviceability checks without dismantling the weapon from launch platform are reported in literature [7]. Test systems to perform comprehensive evaluation of laser seekers in terms of checking their immunity to false PRF codes, mixed code response, sensitivity etc. have also been reported [8]. These systems don't have the capability to test the efficacy of the laser seeker in the presence of commonly deployed countermeasures. This paper discusses an advanced test system that can be used to comprehensively evaluate efficacy of laser seekers in the presence of a variety of countermeasures.

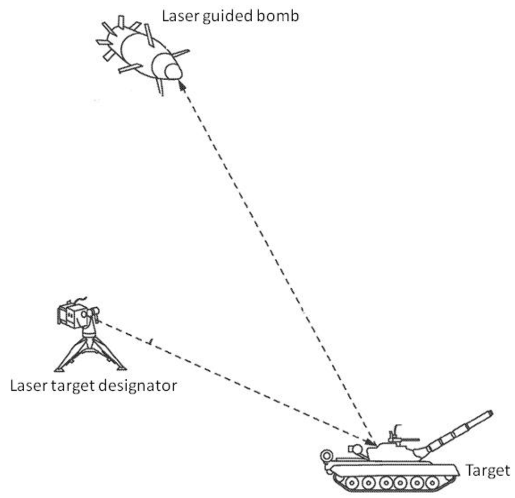

Figure 1. Laser guided bombs delivery concept for land based target designator and aerially delivered munitions

2. Design Concept

Computation of typical laser power levels available at the laser seeker cross-section close to the maximum guidance range and blind range for a laser guided munitions delivery operation are reported in literature. These figures are in the range of 5 - 10 μW/cm^2 close to the terminal guidance range of 5 – 6 km and 10 - 50 mW/cm^2 close to the blind range of 100m [8]. This gives a fairly good idea of the weakest and the strongest laser power level likely to be seen by the laser seeker front end. In the presence of countermeasures, laser seeker is likely to encounter two laser radiations; first scattered from the intended target due to laser target designator and the second scattered from dummy target due to decoy laser. While the former is the genuine laser radiation the guided munitions would want to lock on to; the latter is employed to deceive the munitions away from the intended target. The decoy laser radiation may be Time-Synchronous, Advanced Time-Triggered or Delayed Time-Triggered with the designator radiation.

2.1. Problem Definition

The aim of the system is to test the laser seeker performance in presence of countermeasures. This involves use of two lasers to simulate the designator and the decoy laser signatures.

The test system design is driven by the objective of building capability to evaluate the efficacy of laser seekers in a variety of possible countermeasure scenarios in addition to performing the usual serviceability check by establishing PRF compatibility. The test system is required to generate two radiations simulating the actual designator radiation and the dummy target radiation. In addition to simulate the effect of smoke grenades and decoy laser, radiation simulating the designator radiation will be switched off for 3-4 seconds before switching on the radiation corresponding to decoy laser.

2.2. Design Approach

The test system design is configured around two microprocessor-controlled externally triggered high bandwidth laser diode modules. One of the laser modules represents the laser target designator radiation as received by the laser seeker after scattering from target. The other laser represents the decoy laser radiation as received by laser seeker after getting scattered from dummy target. The two laser beam axes make angle of about 2° - 10° to simulate realistic battlefield conditions. If the dummy target were located at about 200 m from the intended target; the decoy laser radiation after scattering from dummy target in the direction of incoming guided munitions would make an angle of 2° (at 5 km) and 10° (at 1 km). Both lasers are controlled by an embedded circuit that generate the desired combination of the pulse trains used to trigger the two laser modules to simulate different countermeasure scenarios. The laser has an output power of 50mW. The outputs of both the lasers are fed to beam expanders to make a spot size of 80mm at the seeker head. Filter wheel assembly is used to control the power density levels of both the lasers. The various ND filters are used to control the power densities to 1mW/cm^2 (No filter), 100μW/cm^2 (OD 1 filter), 50μW/cm^2 (OD 1.3 filter), 10μW/cm^2 (OD 2) and 1μW/cm^2 (OD 3 filter). Figure 2 shows the schematic arrangement of the system.

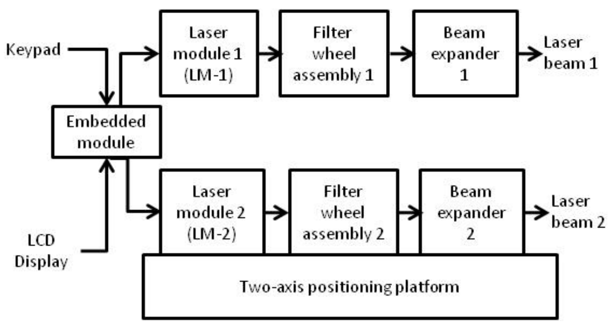

Figure 2. Block schematic arrangement of test system

2.3. Hardware Used

Laser module-1 (LM-1) and laser module-2 (LM-2) are configured around digitally modulated laser module IQ2H from M/s Power Technology. The laser modules are externally triggered and the laser pulse width is equal to the width of trigger pulses. The wavelength spectrum of the laser module is shown in Figure 3.

The 3 mm circular beams produced by laser modules pass through the filter wheel assembly and then to their respective beam expanders. Each beam expander has 30X magnification. Laser module-2 along with its beam expander is mounted on 2-axis positioning platform. This allows variation of angle between the beam axes of the two laser modules. The embedded circuit is interfaced with a key pad (Part No.: 83AB1-101, Make: Grayhill) and an LCD display 16×2 (Part No.: PC0802ARS-A, Make: Powertip). The control sequence is entered from the key pad. The embedded circuit is configured around a PIC microcontroller (Part No.: PIC18F8722). It generates the desired pulse trains for both the laser modules.

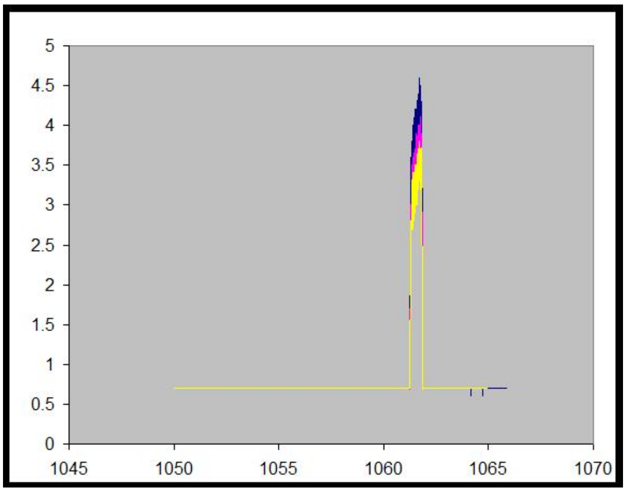

Figure 3. Wavelength Profile of Laser Module (IQ2H)

2.4. Assumptions

The seeker sees scattering from two spots only. There are no multiple reflections/ scattering from nearby targets of locations.

3. Test and Evaluation Methods

The following test cases will be studied:

Scenario-1: A weak genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Time-Synchronous with decoded genuine signal.

Scenario-2: A weak genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Time-Synchronous with decoded genuine signal.

Scenario-3: A strong genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Time-Synchronous with decoded genuine signal.

Scenario-4: A strong genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Time-Synchronous with decoded genuine signal.

Scenario-5: A weak genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Advanced Time-Triggered with reference to decoded genuine signal.

Scenario-6: A weak genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Advanced Time-Triggered with reference to decoded genuine signal.

Scenario-7: A strong genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Advanced Time-Triggered with reference to decoded genuine signal.

Scenario-8: A strong genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Advanced Time-Triggered with reference to decoded genuine signal.

Scenario-9: A weak genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Delayed Time-Triggered with reference to decoded genuine signal.

Scenario-10: A weak genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Delayed Time-Triggered with reference to decoded genuine signal.

Scenario-11: A strong genuine signal from the target coupled with a weak decoy laser signal and decoy laser signal Delayed Time-Triggered with reference to decoded genuine signal.

Scenario-12: A strong genuine signal from the target coupled with a strong decoy laser signal and decoy laser signal Delayed Time-Triggered with reference to decoded genuine signal.

Scenario-13: The laser radiation from the designator is blocked before firing the decoy laser signal. The decoy laser signal can be edge-matched, Advanced Time-Triggered or Delayed Time-Triggered with respect to the designator signal.

3.1. Test Parameters

The test parameters to be tested are the LOCK ON capability of the laser seeker and the concept of decoying the laser seekers.

3.2. Advantages & Limitations:

The advantages of the test system are that the laser seeker performance can be tested in presence of countermeasures. The limitations are that the performance of seeker is tested under lab conditions and presence of ambient light might lead to slight modifications in results.

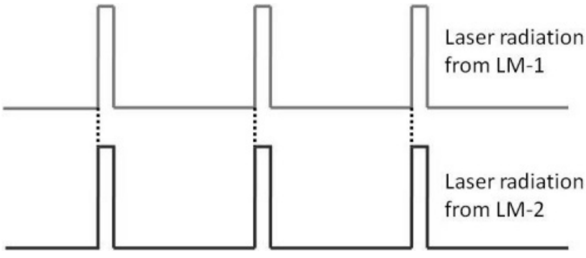

Figure 4. Time-Synchronous trigger pulse trains for LM-1 and LM-2

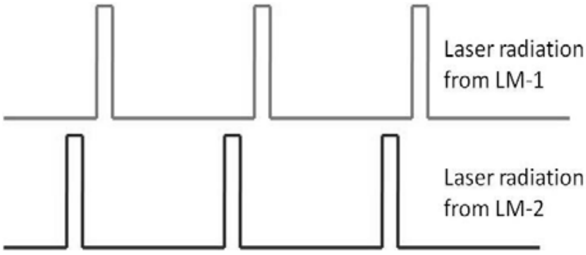

Figure 5. Advanced Time-Triggered pulse trains for LM-1 and LM-2

The prototype was made to test a typical laser seeker head in 13 different countermeasure scenarios outlined earlier. In addition to these tests, the prototype was also used to perform PRF compatibility, false code response and mixed code response tests. The results thus obtained were similar to those reported earlier [8]. Test results are summarized in Table 1 to Table 18. Each test was performed by taking two measurements at three different PRF codes. Figure 4 shows the Time-Synchronous trigger pulse trains from LM-1 and LM-2. The Advanced Time-Triggered pulse train sequence as shown in Figure 5 has LM-1 pulse train delayed from LM-2 pulse train by 1 – 4 µs. The Delayed Time-Triggered pulse train sequence as shown in Figure 6 has LM-2 pulse train delayed from LM-1 pulse train by 1 – 4 µs. The delay time is chosen keeping in view the ± 4 µs window that is available to penetrate the seeker after it has detected the PRF from the designated target.

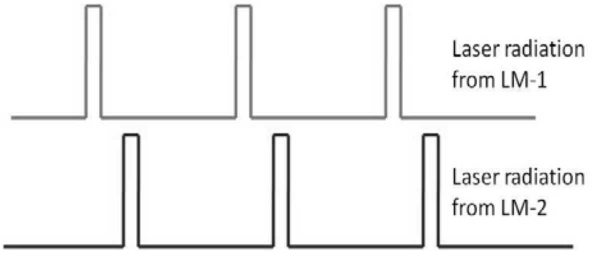

Figure 6. Delayed Time-Triggered pulse trains for LM-1 and LM-2

Table 1

Power density set of laser module-1 (LM-1): 100 µW/cm^2 Power density set of laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 2

Power density set on laser module-1 (LM-1): 10 µW/cm2 Power density set on laser module-2 (LM-2): 100 µW/cm2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks on to LM-2 radiation
2.	50.000	50.000	Seeker locks on to LM-2 radiation

Table 3

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 10 µW/cm^2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks on to LM-1 radiation
2.	50.000	50.000	Seeker locks on to LM-1 radiation

Table 4

Power density set of laser module-1 (LM-1) : 100 µW/cm^2 Power density set of laser module-2 (LM-2): 30 µW/cm^2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 5

Power density set of laser module-1 (LM-1) : 30 µW/cm^2 Power density set of laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 6

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 7

Power density set on laser module-1 (LM-1): 10 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 8

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 10 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 9

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 30 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 10

Power density set on laser module-1 (LM-1): 30 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 11

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker shuttles between LM-1 and LM-2 radiation
2.	50.000	50.000	Seeker shuttles between LM-1 and LM-2 radiation

Table 12

Power density set on laser module-1 (LM-1): 10 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks on to LM-2 radiation
2.	50.000	50.000	Seeker locks on to LM-2 radiation

Table 13

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 10 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks onto LM-1 radiation
2.	50.000	50.000	Seeker locks onto LM-1 radiation

Table 14

Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 30 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks onto LM-1 radiation
2.	50.000	50.000	Seeker locks onto LM-1 radiation

Table 15

Power density set on laser module-1 (LM-1): 30 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker locks onto LM-2 radiation
2.	50.000	50.000	Seeker locks onto LM-2 radiation

Table 16

Blocking the LM-1 radiation Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2, 30 µW/cm^2, 10 µW/cm^2 Pulse trains: Time-Synchronous (Refer to Figure 4)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker changes to LM-2 after blocking LM-1 at all power densities
2.	50.000	50.000	

Table 17

Blocking the LM-1 radiation Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2, 30 µW/cm^2, 10 µW/cm^2 Pulse trains: Advanced Time-Triggered (Refer to Figure 5)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker changes to LM-2 after blocking LM-1 at all power densities
2.	50.000	50.000	

Table 18

Blocking the LM-1 radiation Power density set on laser module-1 (LM-1): 100 µW/cm^2 Power density set on laser module-2 (LM-2): 100 µW/cm^2, 30 µW/cm^2, 10 µW/cm^2 Pulse trains: Delayed Time-Triggered (Refer to Figure 6)			
S. No.	**PRF code set on Laser seeker (ms)**	**PRF code set on LM-1 and LM-2 (ms)**	**Lock-on Status**
1.	100.000	100.000	Seeker changes to LM-2 after blocking LM-1 at all power densities
2.	50.000	50.000	

4. Conclusion

This paper presents a new design concept for testing efficacy of laser seekers in the presence of countermeasures in addition to performing routine functionality checks. A test system was successfully developed that could be effectively utilized for testing of laser seekers. The seeker of foreign origin was tested extensively using the test system. The seeker was effectively decoyed using the post trigger logic. The same test system can also be used for testing seekers of different makes. However the system did not generate solar background noise signal. Hence, the performance of the seeker was tested in lab conditions. Futuristic test systems could generate radiation corresponding to solar radiation to further check the laser seekers.

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