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REVIEW PAPER

Pre-flight Functionality Check to Enhance Mission Efficacy of Precision Guided Munitions

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ABSTRACT

Precision-guided munitions (PGMs), because of their precision strike capability, are used extensively in the modern warfare. The efficacy of the mission is critically dependent on the successful deployment of the weapon. To ensure high level of effectiveness of these sophisticated weapons, these must be tested at regular intervals. Periodic functionality checks of these weapons are carried out using comprehensive characterisation systems. In addition to comprehensive testing, pre-flight functionality checks with the weapon strapped on to the launch platform using portable test systems should be carried out. These functionality checks, also referred to as serviceability checks, perform Go/No Go testing of the weapon by focusing on one or two vital parameters of the guided weapon. Pre-flight functionality check of PGM allows a quick appraisal on the functional status of the vital operational parameters of relevance to efficacy of the mission. This review highlights the parameters that need to be checked, both for comprehensive testing of these weapons on a periodic basis and also those required for pre-flight functionality or readiness checks. International systems available for the purpose have also been reviewed, vis-à-vis, their capabilities and limitations to perform the two types of tests with particular emphasis on the pre-flight functionality checks with guided weapon in strap-on condition. Some alternative design approaches have also been proposed.

Keywords: Precision-guided munitions (PGM), laser-guided munitions, IR-guided missiles, pre-flight functionality checks, Go/No Go testing, seeker, PRF code, IR seekers, guided weapons

1. INTRODUCTION

Laser-guided munitions (bombs and missiles) and IR-guided air-to-air missiles, due to their precision strike capability, are the widely exploited precision-guided munitions on airborne platforms such as fighter aircraft and attack helicopters. These guided weapons have proved their lethality and efficacy beyond doubt during the conflicts in the not too distant past [1,2]. In fact, these sophisticated weapons are very expensive and are of great tactical importance; it becomes all the more important that their effectiveness is nearly guaranteed by testing these at regular intervals [3].

Though comprehensive testing of these weapons in the simulated battlefield conditions may be done on a periodic basis; there is always a need for having portable test systems that could perform pre-flight functionality checks with the weapons strapped on to the launch platform. These functional checks, also referred to as serviceability checks, perform Go/No Go testing of the weapon by focusing on one or two vital parameters of the guided weapon. These tests when performed just before the mission take-off, give that extra bit of confidence to the mission crew on the strength of the weaponry they are carrying along with. Not only this, these tests may sometimes throw a surprise or two, for instance, by revealing that the laser-guided bomb was not locking onto the chosen pulse repetition frequency(PRF) code. As a consequence, mission PRF code could be altered to another available one that was functional.

2. LASER-GUIDED MUNITIONS

In laser-guided munitions delivery operation, the target is illuminated, called target designation, by a pulsed solid state laser producing high peak power (typically 5 MW), narrow pulses (typically in the range of 10 ns to 20 ns) with a PRF in the range of 10 Hz to 20 Hz. The laser seeker head in the weapon uses laser radiation scattered from the target to generate information on the angular error, which in turn is used to generate command signals needed to guide the weapon to source of scatter, which is the target (Fig.1). Before the weapon locks on to the scattered radiation originating from the target, it makes sure that the radiation is the intended one. Laser target designator and the laser seeker used in the guided weapon delivery mission use the same PRF code, and the PRF code compatibility check forms the basis of identification of the desired radiation. PRF code compatibility is therefore essential to weapon's functionality and mission success. PRF code is generally chosen to an accuracy of ± 1 μs to 2 μs in time interval between two successive laser pulses. The seeker head front-end deciphers the PRF of the received radiation, and only if the PRF matches with the chosen PRF value within the specified tolerance, it is further

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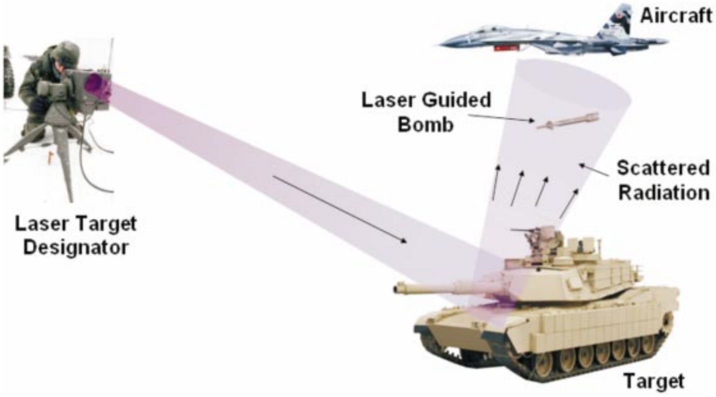

Figure 1. Schematic of laser-guided munitions delivery.

processed to extract information on the angular position of the weapon wrt the target.

2.1 Testing Laser-guided Munitions

Testing laser-guided munitions primarily means testing of its guidance unit. Seeker head is the most important component of the guidance unit. Establishing functionality of the guided weapon therefore zeros down to establishing functionality of seeker head. Major parameters of interest are sensitivity, field-of-view(FOV), response linearity, PRF code compatibility, immunity to false codes, and response to desired code in the presence of false code [4]. While sensitivity of the seeker decides the maximum guidance range for known values of laser target designator parameters, target reflectivity and visibility condition, FOV determines the probability of weapon finding itself within the laser basket at the maximum of the guidance range. PRF code compatibility, as outlined earlier, is the primary requirement for the weapon to function. Immunity to false PRF codes and capability to stay locked on to the desired code in the presence of false codes enhance the probability of target hit. Response linearity predominantly decides the circular error probability (CEP).

Even if the sensitivity were a little poorer, perhaps due to degradation of front-end optics or detector's response, and the seeker were susceptible to PRF codes adjacent to the chosen code or even if the FOV were less than the desired value, the weapon could still home on to the intended target provided the PRF code programmed in the seeker head matched with the one of received scatter. On the other hand, even if all these parameters were as per specified values, weapon would have no chance of hitting the target and would go completely haywire if the seeker PRF code did not match with that of the laser radiation produced by laser target designator.

In view of the above, PRF code compatibility check could easily be singled out for performing pre-flight functionality check whereas other parameters such as sensitivity, FOV, false code immunity, mixed code response, response linearity etc. could be checked only as a part of comprehensive testing exercise carried out on a periodic basis.

2.2 International Test Systems

Test systems for carrying out functionality checks of precision guided munitions are offered by manufacturers of these weapons. Mission readiness test set (MRTS) type no. TTU 594A/E from M/s Lockheed Martin Corporation, designed to perform go, no-go verification of the Paveway-II class of laser-guided weapons is an example. There are other companies engaged in the manufacture of a wide range of opto-electronic simulators and sensors for a variety of test and evaluation functions. These companies, though not engaged in manufacture of precision-guided munitions (PGM), offer test systems suitable for both comprehensive characterisation as well as pre-flight functionality checks. Geotest-Marvin Inc. and CI Systems are two such companies.

Mission readiness test set shown in Fig. 2 is a man-portable, self-contained test set up used to perform go no-go type of functionality check of Paveway-II (Fig. 3) class laser-guided weapons. During test, laser radiation simulating the return signatures of the laser designated target is fibre coupled to the front-end of the seeker head as shown in Fig. 4.

The photograph shows the test being performed in the lab. Though the system has all the desirable features

Figure 2. Mission readiness test set (MRTS) from M/s Lockheed Martin Corporation.

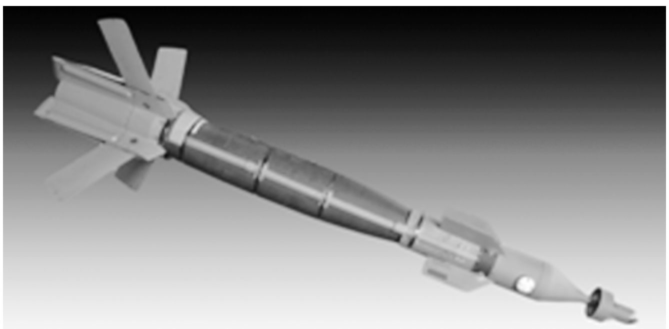

Figure 3. Paveway-II class of laser-guided bomb.

Figure 4. Laser seeker head being tested with MRTS.

of being portable and user-friendly and has an in-built display to show response of seeker to different inputs; it suffers from limited usability to only a certain class of laser-guided weapons. For instance, one cannot use MRTS to test Hellfire laser-guided missiles. Also, it cannot be used to check seeker's immunity to any user-programmed PRF codes. The test set up can be used to check the response of the seeker to only discrete set of NATO PRF codes. In addition, it is also not possible to check seeker's sensitivity performance with this test set up.

Another test system designed to test laser-guided munitions is the laser source simulator (LSS) type MT 1888/1888A from Geotest-Marvin Inc (Fig. 5).

Figure 5. Laser source simulator type MT 1888A from M/s Geotest-marvin Inc.

It is a handheld device that simulates the return signatures from a laser-designated target. The device operates at 1064 nm and produces a maximum power of 0.6 mW spread over the entire laser beam having a divergence of 500 mrad. The output power is low enough (class-I classification) to be used without protective safety goggles. The device is field programmable and the desired PRF code can be selected from the membrane key pad provided for the purpose. The device under test (DUT) to simulator distance is recommended to be in the range of 0.6 m to 3.0 m. Divergence specification of 500 mrad ensures that the seeker head optics is always over spilled. Power density levels produced by the simulator at the seeker plane are typical of the sensitivity figures of the state-of-the-art laser seekers.

The simulator can not however be used to check the seeker for its full dynamic range. Laser seeker typically receives a power density of the order of tens of mW/cm^2 close to its blind range. A test device that simulates the return signatures of the laser designated target at two different power density values, one simulating the maximum terminal guidance range and the other simulating the blind range would be far more useful. Also, if the device generated a collimated beam with a spot size to over spill the seeker head rather than a highly diverging laser beam as is the case with MT 1888/1888A; it would simulate the real battlefield scenario. Such a device could possibly be configured around a high bandwidth laser diode module operating at 1064 nm. Large bandwidth allows generation of few nano seconds wide laser pulses. A suitable circuit could be used to generate drive waveform at desired pulse repetition rate and resolution. Yet another improvement that can possibly be incorporated is the inclusion of a visible laser-pointing beam aligned to be at the centre of the IR beam. It will allow the test IR beam to be properly aligned to the seeker front-end particularly during nighttime and also when the target seeker is a few meter away from the simulator.

Going a step further, using two independent laser beams that are combined to produce the output beam and where the PRF codes of the two beams can be independently chosen would allow the user to perform the mixed code test too [5].

To sum up, the simple test device were modified to incorporate

(a) Variable power density feature either by changing the divergence or power level or both to offer at least two power density levels.
(b) Visible laser beam at the centre of IR beam for easy alignment.
(c) Two IR laser beams with independent PRF code programmability and optically combined to produce the test beam.
(d) Collimated laser beam rather than a diverging beam.

The device would simulate not only the real battlefield conditions, it would also allow comprehensive and pre-flight testing of this important class of precision-guided weapons.

3. INFRARED-GUIDED MISSILES

Infrared-guided missiles make use of IR emission corresponding to the thermal signatures of the exhaust and the mainframe of the target aircraft to home on it. Emission in 3-5 μ and 8-12 μ bands is characteristic of electromagnetic emission from jet exhaust and mainframe of the aircraft. Figure 6 shows the wavelength bands emitted by a typical fighter aircraft target due to its thermal signatures. Spectral content of IR emission as received by IR seeker head as shown in Fig.7 is the superposition of spectral emission of the aircraft on the spectral response of the atmosphere [6]. This wavelength signature is judiciously

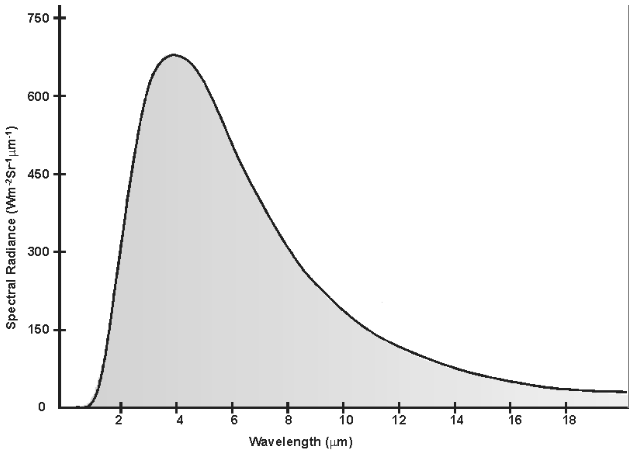

Figure 6. IR emission spectrum of typical fighter aircraft target.

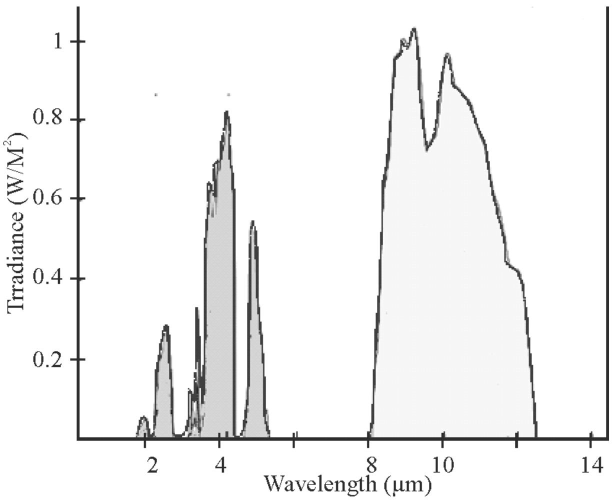

Figure 7. IR signatures as received by IR seeker head.

used in guidance of air-to-air and surface-to-air IR-guided missiles.

Infrared-guided missiles developed in 70's and 80's used single-colour IR seekers employing 3-5 µ band. MAGIC-series in Fig. 8 of IR-guided air-to-air missiles from France and R-73-series of IR-guided air-to-air missiles from Russia are some examples. State-of-the-art IR-guided missiles use two-colour-seekers that employ both 3-5 µ and 8-12 µ bands to offer improved false alarm rejection and immunity to deception by flares.

Figure 8. MAGIC IR-guided missiles.

Figure 9. Python IR-guided missile from Israel.

Python from Israel (as in Fig. 9) and RVVAE from Russia are examples of IR missiles using two colour seeker heads. Another emerging trend is the use of imaging IR seekers even in surface-to-air and air-to-air IR-guided missiles though their use is primarily in short range anti-tank IR-guided missiles.

Also, both surface-to-air and air-to-air IR-guided missiles receive target's IR signatures in the presence of background radiation from the sky. The seeker head should be able to discriminate between IR signatures of the background and those of the target.

3.1 Testing IR-guided Missiles

When it comes to testing IR-guided missiles, be it pre-flight functionality check or comprehensive characterisation, the parameters include spectral matching of generated IR signatures with those of the target as known to the seeker, response of seeker head to target signatures in the presence of static IR background noise, immunity to deception by flares, and FOV. Out of these four parameters, spectral matching can be singled out as the one to be used for pre-functionality checks while all the four parameters should be evaluated in the case of comprehensive characterisation.

The kind of devices needed to perform pre-functionality checks and comprehensive characterisation would need to address the requirements of IR-guided missiles employing single-colour seekers and those employing two-colour seekers. This implies that the device designed to carry out pre-functionality checks would need to have option of generating either 3-5 µ band with desired relative amplitudes of the two bands within the 3-5 µ window (Fig. 10) or 3-5 µ and 8-12 µ bands simultaneously, similar to the signatures shown in Fig. 7.

In essence, the device used to perform pre-functionality test checks the lock-on sensitivity of the weapon and its ability to perform satisfactorily in the presence of static background noise. In some cases, it may only check the lock-on sensitivity.

Comprehensive characterisation is also very important for the following two reasons.

(i) It provides required inputs during deign and development phase of IR seekers.

(ii) Complete understanding of IR seeker in terms of its response to target's IR signatures against different backgrounds.

Infrared flares of different temporal and spectral profiles

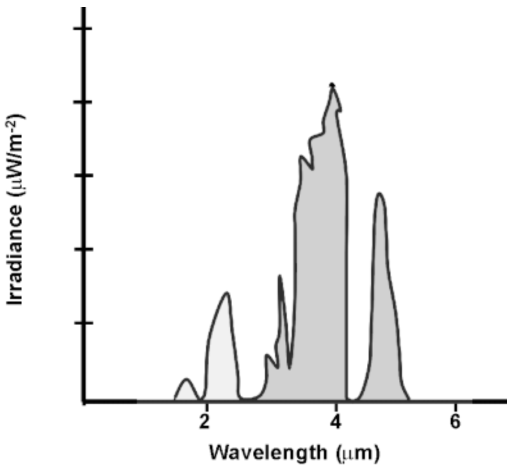

Figure 10. Relative amplitudes of two bands in single-colour IR seekers.

provide vital design inputs for development of efficient flares to be used as countermeasures against IR-guided missiles. To summarise, the spectral output modes of the test system for pre-functionality or serviceability checks would include

(a) 3-5 μ output with static background,
(b) 8-12 μ output with static background, and
(c) 3-5 μ and 8-12 μ bands simultaneously with static background.

On the other hand, the spectral output modes of the test system for comprehensive characterisation in addition to the above modes would also include mode-a, mode-b and mode-c with selected IR flare signatures.

3.2 International Scenario

Infrared target simulators designed to characterise IR-guided missiles are available from international manufacturers such as CI Systems, Israel; Geotest-Marvin Inc, USA, and SBIR, USA. The test systems offered by these companies range from simple IR sources for checking lock-on sensitivity of single-colour and two-colour IR seekers to more elaborate systems that generate an IR scene, which includes a static background, target, and flare signatures. Some popular systems are:

(a) *Target infrared simulator (TIRS) from M/s CI Systems*.

One such system is the target infrared simulator (TIRS) from M/s CI Systems. It is a computer-controlled table-top test system that simulates an IR scene, which includes static background, moving/growing target, and moving/growing flare signatures. The system is designed for characterisation of single-colour IR seekers operating in 3-5 μ band. The target and background signatures are produced by IR slides. Background generating slide offers user-selectable background signatures in the temperature range 25 °C to 180 °C with a resolution of 0.5 °C. Target signatures are also selectable for a wide range of target types including tank, aircraft, ship, etc. Flare signatures correspond to temperature range 50 °C to 500 °C with a resolution of 1 °C. As evident, the system has all the necessary features to carry out extensive testing of IR seeker characteristics. The only limitation seems to be its applicability to only single-colour IR seekers. Also, looking at the nature of test set up, the system is not portable enough to be used for performing pre-functionality checks on single-colour IR-guided missiles in strap-on condition.

(b) *Infrared target generator for CI Systems*

Another similar system from CI Systems is the infrared target generator (IRTG) used for hardware in-the-loop-testing of missile guidance subsystems of single- and two-colour IR-guided missiles for target acquisition and tracking capability and immunity to countermeasures such as flares.[7] The IR scene generated by the system includes a static background, a dynamic target, and flare. Figure 11 shows the photograph of the system. The system is mounted on a flight motion simulator during the characterisation process. Again, the system, though capable of generating all the required parameters as seen by the seeker in a real deployment scenario, is not portable to be used for pre-flight functionality checks on IR-guided missiles in strap-on condition.

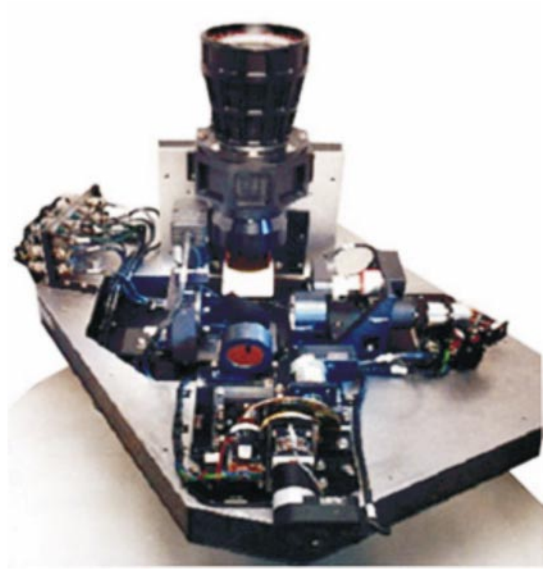
Figure 11. Infrared target generator (IRTG) from CI systems.

(c) *MTS-916 target simulator from M/s Geotest-Marvin Inc*.

Yet another test system designed for carrying out functionality checks of guided missiles is the MTS-916 target simulator from M/s Geotest-Marvin Inc. It is a modular target simulator that supports TV/CCD, IR, and laser-seekers used in AGM-65 and TGM-65 Maverick missiles. The test is system is offered in multiple configurations to support missiles with only TV/CCD seekers (MTS-9161), only IR seekers (MTS-916-2), both TV/CCD and IR seekers (MTS-916-3), and only laser seekers (MTS-916-4). Different configurations of the test system comprise a mounting unit common to all the four configurations,

Figure 12. MTS-916 target simulator.

an optics unit, that is a visual optics unit in the case of TV/CCD seekers and an IR optics unit in the case of IR seekers and an electronics unit that controls the optics units. Figure 12 shows the photograph of integrated setup. The IR target simulator configuration MTS-916-3 of the test system generates signature both 3-5 μ and 8-12 μ bands and therefore can be used to perform functionality checks on both single-colour and two-colour IR-guided missiles. The system is primarily intended for performing readiness checks and does not simulate target signatures in the presence of static IR background and nor does it test the immunity of the missile to dynamic flares. Also, the system is not portable or configured the way it should have been to be conducive to performing readiness checks with missile in strap-on condition.

One possible approach to building a simple device that could perform pre-functionality check on IR-guided missiles is to use blackbody emitter with suitable parabolic reflector for beam collimation, as shown in Fig. 13. An appropriate filter could be used to shape the output spectral profile. An array of such emitters could be used to generate two-colour output spectrums to perform pre-functionality check on missiles using two-colour IR-guided seekers. In that case, one would need to use 3-5 μ and 8-12 μ bandpass filters.

One could also use an array of mid-IR LEDs covering the desired spectrum of 3-5 μ as shown in [Fig. 14] with

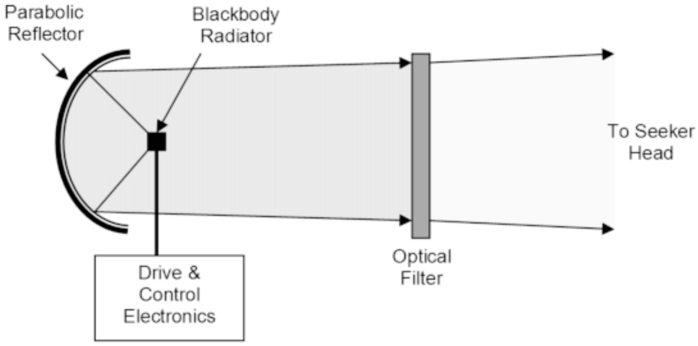

Figure 13. Blackbody emitter with parabolic reflector.

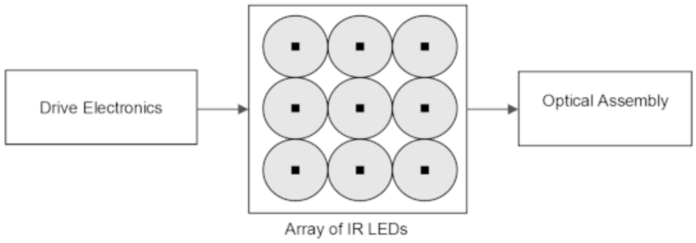

Figure 14. Array of mid-IR LEDs to generate 3-5 μ spectrum.

each LED in the array generating a specific wavelength. A number of manufacturers offer mid-IR LEDs. One such set of LEDs comprising LED-30SC, LED-32SC, LED-34SC, LED-36SC, LED-38SC, LED-42SC, LED-47SC and LED-54SC from M/s Scitec, UK with corresponding peak emission wavelength of 3.0 μ, 3.2 μ, 3.4 μ, 3.6 μ, 3.8 μ, 4.2 μ, 4.7μ, and 5.4 μ meets the requirement. These LEDs are available with collimating reflectors and have a typical line width of 0.5 μ. Overlapping beams from these LEDs could be shaped to produce the desired 3-5 μ output required to perform pre-functionality check on single-colour IR-guided seekers.

4. CONCLUSIONS

There are test systems that very closely simulate the laser or IR signatures of the target. Some of these have been briefly outlined. These systems however are not portable to be suitable for doing readiness checks on the weapons in strap-on condition. Few systems particularly designed for strap-on testing usually do not simulate the true signatures of the target. In case of test systems for IR-guided missiles, these invariably use blackbody emitters as source of IR radiation with peak amplitude at 2-3 μ and a tail that has significant amplitude of about 20 μ. When such a device is used to perform readiness checks on single-colour and two-colour IR-seekers, it no longer exposes the seeker head to what it would have seen in the actual deployment. Though there are plenty of test systems to perform comprehensive characterisation and readiness checks of IR seekers in table-top setup, the test systems available for strap-on testing do not generate the true signatures. Therefore, there is need for development of portable test systems that have the compactness and portability required for strap-on testing and yet correctly simulates the target signatures. An array of IR emitters with suitable optics and control and drive electronics for an IR target simulator would serve a better purpose. Array of mid-IR LEDs with closely spaced peak emission wavelengths could also be used as an alternative design approach. Similarly, two laser beams with independent PRF selection and combined into a single collimated beam with suitable optics to over spill the seeker head would surely make a true laser seeker tester. There is a need to trade-off between the compact but oversimplified test systems and comprehensive but bulky test systems.

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