MS

Systems for testing multi imaging/laser systems

Fig. 1. Photo of several versions of MS3 test system different aperture and test capabilities:
a) MS5120, b)MS30200 c) MS60600

1 Introduction

Multi imaging/laser systems are systems built by combining one or more imagers with one or more laser systems. Most advanced multi imaging/laser systems are built from a long series of imaging/laser blocks like thermal imager (or two thermal imagers), color VIS camera, low light VIS-NIR camera, SWIR imager, laser range finder, laser designator, and laser pointer located on a mechanical platform. Most typical multi sensor systems are built in form of a set if three sensors (thermal imager, VIS-NIR camera and laser range finder) located on a mechanical platform. The latter platform can be stabilized gimbal type or non-stabilized one/two arms angular stage.

Testing multi imaging/laser systems is a technical challenge due to several reasons. First, diameter of combined optics of all imagers lasers is often high (up to 500mm in case of gimbal type system or up to 1000mm in case of pan-tilt systems. Second, measurement of a long series of performance parameters of imagers and lasers is needed to characterize total system. Third, precision measurement of boresight errors between different imagers/lasers is needed.

MS systems are the most popular Inframet products and are used in hundreds of laboratories worldwide including top world manufacturers or scientific institutions – see reference list on Inframet website: http://inframet.com/references.htm.

2 What E-O systems can be tested?

MS series systems can enable extensive testing and boresighting of virtually all multi-imaging/laser E-O systems offered on market (Fig. 2). in detail, MS systems have been designed for testing/boresight of four main groups of EO imaging/laser systems:

a) gimbal type multi imaging/laser systems;
b) pan-tilt type multi imaging/laser systems;
c) box type multi imaging/laser systems;
d) binocular/monocular portable multi imaging/laser system.

MS systems can be also used for testing stand alone long/medium range imagers or laser systems (LRFs, designators, pointers, directional receivers) but specialized test stations (DT, TVT, ST, LUNI, LTE, L64) are recommended. It should be also noted that MS systems are not optimal for testing short range (wide FOV) imagers.

Fig. 2. Example multi imaging/laser EO systems that can be tested using MS series test systems

3 Test capabilities

Test capabilities (max aperture of tested system and number of measured parameters) of MS depend on version. Max aperture of system to be tested can vary from about 120mm (systems for testing small drones) to about 600mm (systems for testing huge gimbal type multi imaging/laser systems. Optionally huge pan-tilt two arm systems multi imaging/laser systems of total optical aperture up to 1000mm can be tested. Max aperture of system to be tested is determined by aperture of collimator used as part of test system.

Number of measured parameters depends on configuration of MS system but in the most expanded version following parameters can be measured:

1. Thermal imagers: MRTD, MTF, SiTF, NETD, FOV;
2. VIS-NIR cameras: resolution, MTF, FOV, MRC;
3. SWIR cameras: resolution, MTF, FOV, MRC;
4. Pulsed lasers (transmitters of LRFs/designators): pulse energy, pulse peak power, PRF, pulse time width;
5. Pulsed lasers (receivers of LRFs/designators): variable distance range, distance accuracy;
6. CW lasers (laser pointers): mean power, divergence angle;
7. Boresight capabilities: angles between 1)imager to imager (TI to VIS-NIR), 2)laser to imager (laser to TI or laser to VIS-NIR camera), 3)imager to reference mechanical plane (option).

4 How MS systems are built?

MS systems are modular systems build using over 30 exchangeable modules. However, all these modules can be grouped into seven main blocks:

1. Multispectral image projector;
2. Boresight tools;
3. Meters of radiometric/temporal properties of laser;
4. Laser profilometer;
5. Optical pulse generator;

6. Image acquisition and computing block;
7. Mechanical platforms (optional).

Multispectral image projector is an optical system that project into direction of tested imager some reference images in several spectral bands (MWIR/LWIR, VIS-NIR and SWIR). Image projector is built as a set of six main modules: collimator, rotary wheel, blackbody, light source, TI targets, VIS-SWIR targets. in some versions of MS system typical rotary wheel is replaced by focusing-rotary wheel. The latter wheel enables not only exchange of targets at collimator focal plane but also to regulate position of the targets along collimator axis (focusing).

Boresight tools are a block that support measurement of two main types of boresight errors:

1. Laser to imager (TI imager or VIS-NIR camera);
2. Imager to reference mechanical plane (option).

The first task is achieved using a set of laser viewing cards located at collimator focal plane. The cards enable conversion of SWIR light of typical lasers into visible light/thermal radiation and the laser spots at collimator focal plane become visible for thermal imagers or VIS-NIR cameras. The second optional task is achieved using special autocollimator located inside the collimator that emits laser beam to be reflected by small mirror attached to imager reference flat wall (needed only in case of special thermal sights having such reference wall).

Task of the third block is to enable measurement of parameters that describe laser radiometric/temporal properties: pulse energy, pulse peak power, mean power, pulse repetition frequency, pulse time width, missing pulses. This aim can achieved using several optical meters of different level of measurement capabilities (number of parameters) and different level of automation/computerization.

Laser profilometer is a block to enable measurement of two-dimensional intensity profile of laser beam at collimator focal plane (laser spot) and calculation of divergence angle of tested laser. The aim is achieved by using SWIR imager of ultra high dynamic capable to capture such profiles of lasers used in typical LRFs, laser designators and laser pointers.

Optical pulse generator is a block to enable simulation of a target irradiated by a series of optical pulses in order to enable distance accuracy/range tests of laser range finders. This task is achieved by emitting optical pulses of regulated time delay into direction of tested LRF.

Image acquisition and computing block is a block to carry out acquisition of video image generated by tested imagers, carry out image processing and to calculate parameters of tested imagers and boresight errors. This task is done by a PC set with installed frame grabber cards and a set of control/image analysis computer programs.

Finally, mechanical platforms are an optional block built typically as a set of two system: large anti-vibration table and a small angular stage. The table is used as a platform for test system and tested system. The stage is used for regulation of angular position of tested imagers/lasers.

5 List of blocks of MS system

MS test system is a modular system built in most advanced version using a long series of modules:

1. CDT off axis reflective collimator (collimators of different aperture, focal length and optical quality are available for different applications);
2. MRW motorized rotary wheels (version of rotary wheel is determined by version of collimator, its FOV and number of targets);
3. TCB differential blackbody (versions of different size) – optionally DCB color blackbody;
4. Set of IR targets (different configurations are possible);
5. VIS-SWIR light source: 1) LS-MOH light source or 2) LS-MOL light source (versions of different size emitters to fill collimator FOV);
6. Set of VIS targets (different configurations are possible);
7. Laser boresight tools: set of LSC laser sensing cards (two different sizes), set of OA optical attenuators, OH mechanical holder for attenuators/meter probes;
8. Set of laser radiometric/temporal meters: COE pulse energy meter, COP mean power meters, COPO integrated meter of pulse energy/power meter, or OSA optical signal analyzer;
9. Laser profilometer: LSR10;
10. Optical pulse generators: LMOB or LOPG;
11. SSM mirror stage (control of position secondary mirror);
12. PC – typical PC working under Windows operating system (laptop or desktop PC are delivered);
13. Set of frame grabber cards;

14. Set of control programs: Collimator Control, Blackbody Control, LS Control, Target Control;
15. Set of measurement support programs: SUB-T, SUB-V, TAS-T, TAS-V, OPG, Pulse Browser.

6 Versions of MS systems

MS test systems are a modular system that can be configured into a long series of versions of different test capabilities and price optimized for testing slightly different groups of EO imaging/laser systems.
Choosing proper version of MS system is not an easy task. It can be done in two steps.

1. **Filling questionnaire document and sending it to Inframet;**
2. Careful reading this section and determination code of MS system.

This section talks about the second step.

Concept of code that could precisely describe design / test capabilities of MS system is based on idea to use two part code:

Part 1: describe basic design parameters of collimator used by MS system (collimator code);

Part 2: describe test capabilities of MS system (system code).

6.1 Collimator code

Collimator code (example CDT30200-44-8) is determined by choosing one of collimators from list in Table 1. While combining full MS system then collimator letters “CDT” are exchanged by system letters “MS” to get system code MS30200-44-8.

Table 1. List of models of collimators that can be used to build MS systems

CDT collimator model	Aperture [cm]	Focal length [cm]	Target [mm]	Number of targets	FOV [º]	Collimator F-number	Minimal frequency 4-bar target [lp/mrad]	Minimal frequency: USAF1951 [lp/mrad]	Testing high power lasers
12100-44-8	12	100	44	8	2.47	8.33	0.14	0.50	
15120-44-8	15	120	44	8	2.06	8	0.17	0.60	
15150-44-8	15	150	44	8	1.65	10	0.22	0.75	•
20160-44-8	20	160	44	8	1.54	8	0.23	0.80	•
20200-75-8	20	200	75	8	2.11	10	0.17	0.50	•
25200-44-12	25	200	44	12	1.24	8	0.29	1.00	•
25200-75-8	25	200	75	8	2.11	8	0.17	0.50	
30200-44-12	30	200	44	12	1.24	6.67	0.29	1.00	
30200-75-8	30	200	75	8	2.11	6.67	0.17	0.50	
30300-44-12	30	300	44	12	0.82	10	0.43	1.50	•
30300-75-8	30	300	75	8	1.40	10	0.25	1.50	
35200-44-12	35	200	44	12	1.24	5.71	0.29	1.00	•
35200-75-8	35	200	75	8	2.11	5.71	0.17	1.00	
35350-75-8	35	350	75	12	1.20	10	0.30	0.88	
40240-75-8	40	240	75	8	1.76	6	0.20	0.60	
40240-44-12	40	240	44	12	1.03	6	0.35	1.20	
40400-75-12	40	400	75	12	1.05	10	0.34	1.00	•
45500-107-8	45	500	107	8	1.20	11.11	0.30	1.25	
50300-75-12	50	300	75	12	1.40	6	0.25	0.75	•
50500-75-12	50	500	75	12	0.84	10	0.42	1.25	•
50500-107-8	50	500	107	8	1.20	10	0.30	1.25	
60600-107-12	60	600	107	12	1.00	10	0.36	1.50	

Collimator code delivers information about a series of useful parameters

1. Collimator aperture;
2. Collimator focal length;
3. Target diameter;
4. Number of targets;
5. Effective FOV;
6. Minimal frequency of 4-bar target (testing thermal imagers);

7. Minimal frequency of USAF 1951 target (testing VIS-NIR cameras);
8. Optimization for testing high power lasers.

Collimator aperture gives information on diameter of maximal multi imaging/laser system that can be seen by the collimator (diameter of circle that overlaps optics of all imaging/laser sensor of the tested system).

Information on **focal length is** needed to calculate angular size/spatial frequency of targets located at collimator focal plane. It gives also information on approximate length of the collimator.

Target diameter delivers information how big can be test targets to be projected by the collimator into direction of tested EO system.

Number of targets delivers information on maximal number of target plates that can be inserted into rotary wheel. Higher number of targets enables to carry out in shorter time expanded test that need many targets. Please remember that in case of small patterns multi-pattern targets can be used to increase number of patterns. See details in targets data sheet https://www.inframet.com/Data_sheets/Targets_IR.pdf

Real collimator FOV is angular size of maximal hypothetical target located at collimator focal plane that can be projected by the collimator. It depends mainly on diameter of the secondary flat mirror. This parameter is rarely published because from user point of view more important is effective collimator FOV. It is angular size of target plane that ca9n be inserted to rotary wheel located at collimator focal plane. This parameter determined also indirectly size of radiation sources (blackbody, light source) that must be sufficiently big to fill collimator FOV.

Collimator F-number gives information of relative uniformity of image quality within collimator FOV. All off axis parabolic reflective collimators can project near perfect image of target located in center of collimator FOV (focus point). However, quality of projected image always deteriorate for non-center targets. The level of this deterioration is much higher for collimators of low F-number. Therefore if non center resolution patterns are to be used then collimators high F-number (over about 8) are preferable.

Frequency of minimal 4-bar target / USAF1951 target that can be projected is calculated as minimal frequency (biggest bars) of 4-bar target that can be inserted into angular circle equal to collimator FOV. It delivers direct information what is minimal frequency of 4-bar target that can be used during tests of thermal imagers (approximately also VIS-NIR cameras/SWIR imagers).

However, it is commonly accepted that Nyquist frequency of tested imager should be at least two times higher than frequency of the biggest bar target. Therefore frequency of maximal 4-bar target determines also minimal Nyquist frequency of the tested imagers. The latter Nyquist frequency is simply two times higher comparing to frequency of maximal 4-bar target.

Attention:

1. If two collimator models of the same aperture and different FOV listed in Table can be used for testing imagers of lowest Nyquist frequency then then collimator of lower FOV shall be chosen because such collimator is equipped with rotary wheel with higher number of targets.
2. If none of interesting collimators (proper aperture) cannot fulfill condition then Inframet can deliver customized collimators of bigger FOV (low F-number). However, quality of projected target in total FOV is poor. Therefore if high quality of projected image is required in total FOV then FOV of collimator must be small (below about 2 degree).

Testing high power lasers (long range LRFs/designators) present a challenge to test system as concentrated laser beam can damage secondary flat mirror and laser meters located at collimator focal plane. Therefore for testing such lasers Inframet uses specially modified collimator with switchable secondary mirror having two focal planes. However, this solution can be used only in case of selected models (see mark "●" in last column).

6.2 System code

System design/test capabilities are described using ten digit code that delivers precision information on ten following criterion:

A Collimator grade - maximal Nyquist frequency from imagers to be tested;
B Number of supported video interfaces;
C Blackbody source;
D Thermal imagers tests;
E Light source;
F VIS-SWIR tests;
G Laser boresight tests;
H Laser radiometric/ temporal tests;

I Laser spot tests;
J LRF specific tests.

Precision definitions of ten digit code are shown in Table 2. The columns A-J show what digits are to be chosen to define precisely required version of MS test system.

Table 2. Ten digit code of basic versions of MS systems

	A	B	C	D	E
No	**Maximal Nyquist frequency of tested imagers [lp/mrad]**	**Supported video interfaces**	**Blackbody**	**Tests of thermal imagers**	**Light source**
1	25	No video int.	No blackbody	No tests	No light source
2	100	One video int.	TCB blackbody	Infinity focus	LS-MOH halogen source
3	400	Two video int.	DCB-SEM2 color blackbody	Additionally MRTD	LS-MOL multi LED source
4		Three video int.	DCB-HAL color blackbody	Additionally NETD, MTF, FOV	
5		Four video int.		Customized tests	

	F	G	H	I	J
No	**VIS-SWIR tests**	**Laser boresight tests**	**Laser radiometric/ temporal tests**	**Laser spot tests**	**LRF specific tests**
1	No tests	No tests	No tests	No tests	No tests
2	Resolution, infinity focus	Tests at Low Collimator Protection Mode (LPM)	Pulse energy/mean power meters at collimator output plane	Divergence angle/ 2D spot profile - meter at secondary focal plane (available in HPM only)	Variable distance/distance accuracy – simulation at collimator output
3	Additionally MTF, FOV	Tests at High Collimator Protection Mode (HPM)	Pulse energy/mean power - meter at collimator secondary focal plane (available in HPM only)		Variable distance/distance accuracy – simulation at collimator focal plane (available in HPM only)
4	Additionally MRC		Pulse energy, pulse peak power, mean power, PRF, pulse width – meter at secondary focal plane (available in HPM only)		
5	Customized tests				

The ten digit coding looks complicated and difficult to be used. However, the code is necessary to show precisely what configuration of MS is truly needed. Next, details of design of test system are not needed to determine the code. The user is expected mostly to present basic requirements on system test capabilities (what EO systems to be tested, Nyquist frequencies of tested imagers, and number of parameters to be measured).

Digit 1 means the simplest level of the criterion. Higher digit – more advanced. Therefore there is a very big difference in design and price between simple MS30200-44-12-11-22-22-11-11-11 test system for testing medium range multi imaging system and more sophisticated MS30200-44-12-23-24-24-34-23 for testing long range multi imaging/laser systems.

A Maximal Nyquist frequency

Requirements on quality of image projected by collimator (collimator grade) are determined by maximal Nyquist spatial frequency of tested imagers.

In detail, Nyquist spatial frequency determines maximal spatial frequency (smallest sinusoidal bar patterns) that imager can reproduce perfectly. Nyquist spatial frequency of tested imagers can be easily calculated in two ways: 1)ratio of imager focal length to (in mm) to dimension of pair pixels of image sensor used by the imager (in µm), 2) half of ratio of pixel number (unitless) of image sensor to imager FOV (in mrad unit).

Maximal Nyquist spatial frequency of tested imagers is a near perfect criterion to estimate real requirements on quality of image projected by the collimator. Nyquist spatial frequency of imagers tested using MS systems often vary a lot: from about 0.5lp/mrad (short range imagers) up to about 500lp/mrad (space imagers). Therefore the conclusion is that requirements image projected by the collimator vary a lot and there is little sense to deliver perfectly aligned collimator built using perfectly manufactured mirrors for testing short/medium range imagers (low Nyquist spatial frequency). Therefore Inframet offers three grades of off axis collimators depending on mirror manufacturing accuracy:

A1. HR (high resolution) - manufacturing accuracy P-V not worse than about $\lambda/4$ at $\lambda = 630$ nm;
A2. UR (ultra high resolution) - manufacturing accuracy P-V not worse than $\lambda/8$ at $\lambda = 630$ nm;
A3. XR (extreme resolution) - manufacturing accuracy P-V not worse than $\lambda/12$ at $\lambda = 630$ nm.

HR mirrors are used in typical mass production collimators for testing short/medium range imagers. XR class mirrors are used in collimators for testing space imagers of ultra narrow FOV. UR class are intermediate solution.

Mirrors of higher manufacturing accuracy can potentially generate high quality images only if used in properly aligned collimators. Therefore HR/UR/XR symbols determine not only mirror manufacturing accuracy but also class of aligning of the collimator. Recommendations on collimator grade depending on maximal Nyquist spatial frequency of tested imager is presented in table 3. The user is expected to calculate maximal Nyquist spatial frequency of imagers to be tested and later to choose proper grade of the collimator.

Table 3. Recommended collimator grade depending on maximal Nyquist spatial frequency of tested imagers

Column a (row number)	1	2	3
Nyquist frequency of tested imagers [lp/mrad]	<25	<100	<400
Recommended collimator grade	HR	UR	XR

Attention:
Nyquist frequency in Table is imager frequency in lp/mrad (line pair per mrad unit). It is not image sensor Nyquist frequency in lp/mm unit.

B Supported video interfaces

Tested multi-sensor imaging systems typically generate output image to be analyzed by humans or by software in electronic forms using different video interfaces. This video image must be captured and analyzed to measure parameters of imagers (thermal imagers, VIS-NIR cameras, SWIR cameras).

Long series of video interfaces can be used: analog video, Camera Link, GigE, LVDS, HD-SDI, DVI, HDMI, CoaXPress, USB2.0/3.0, Ethernet and so on. Capturing video image is carried out using specialized frame grabber cards inserted to PC and image acquisition software optimized for specific video interface. Inframet can deliver frame grabbers/software that support approximately up to four video interfaces. If more interfaces are needed then additional PC with frame grabbers is delivered.

C Blackbody source

Three types of blackbodies can be used in MS systems:

C1. No blackbody;
C2. TCB blackbody;
C3. DCB-SEM2 color blackbody;
C4. DCB-HAL color blackbody.

The first one (TCB) is typical differential blackbody to be used as a source of thermal radiation in MWIR-LWIR range when testing thermal imagers.

Two others are DCB series color blackbodies – broadband source of optical radiation having emitter module that simultaneously reflects light emitted by an external shortwave source (VIS-SWIR light source) and emits long-wave thermal radiation in MWIR-LWIR region. The name originates from the fact that it works like a typical blackbody in middle/far infrared range but its emitter appear to be white from middle VIS range to middle SWIR range.

Two types of DCB color blackbody are offered:

1. DCB-SEM2 color blackbody – fusion of typical MWIR/LWIR blackbody with multi LED source emitting in VIS-NIR band;
2. DCB-HAL color blackbody – fusion of typical MWIR/LWIR blackbody with halogen light source emitting in VIS-SWIR band.

DCB blackbodies are strictly needed when testing fused imagers generating thermal imager fused with VIS-SWIR imager. They can be also used in case of typical multi imaging systems (switchable spectrum: thermal imager or VIS-NIR camera or SWIR imager). Further on, DCB color blackbodies eliminate need for specialized light source (column E). However, there are several drawbacks of DCB color blackbodies:

1. Higher price comparing to typical TCB blackbody;
2. Emissivity and uniformity of DCB color blackbodies is slightly lower comparing to typical TCB blackbodies;
3. Maximal luminance of of DCB color blackbodies is significantly lower comparing to specialized light sources (LS-MOH/LS-MOL) listed in column E.

Technical details of TCB blackbodies https://www.inframet.com/Data_sheets/TCB.pdf

Technical details of DCB color blackbodies https://www.inframet.com/Data_sheets/DCB.pdf

Therefore for testing typical multi imaging systems it is recommended typical TCB blackbody and one of light sources proposed in Column E.

D Thermal imagers tests

Test range of thermal imagers is described by a number of parameters that are to be measured using MS test system. Test range can vary from infinity focusing combined with resolution test to measurement series of parameters: MRTD, MTF, SiTF, NETD, and FOV. List of measured parameters can be expanded too.

Test range of thermal imagers is determined by two factors:

1. Types and number of IR targets to be delivered;
2. Number of software modules that support tests

Detail description of codes used in column no D is presented below:

- **D1.** No thermal imagers tests;
- **D2.** IR targets: one 4-bar target of specified frequency is delivered; no software support;
- **D3.** IR targets: set of eight 4-bar targets and software test modules: Blackbody Control program and SUB-T program to support MRTD test are delivered;
- **D4.** IR targets: set of eight 4-bar targets, edge target, dot-cross target. Software test modules: as in D3 but additionally TAS-T program (MTF, SiTF, noise parameters, FOV modules) are delivered;
- **D5.** Customized solutions.

E Light source

Column E specify type of light source to be used for testing VIS-NIR cameras or optionally SWIR imagers. Two types of light sources are offered:

- **E1.** No light source;
- **E2.** LS-MOH -broadband 400-2000nm light source based on halogen lamp with mechanical regulation of light intensity. Approximate color temperature in VIS-NIR band is about 2856K;
- **E3.** LS-MOL – VIS-NIR (400-900nm) light source based on multi LED lamp with electrical regulation of light intensity. Approximate color temperature is about 5000K.

Wider spectral band is main advantage of LS-MOH. Its disadvantages are: short life time of halogen bulbs, low color temperature, slow regulation of light intensity.

Advantages of LS-MOL: long life time of LEDs, high color temperature (similar to solar light), fast regulation of light intensity.

Aperture of both light sources is kept wide enough to fill part of collimator FOV needed to carry out required tests of VIS-SWIR imagers.

F Tests of VIS-SWIR imagers

Test range of VIS-NIR cameras and optional SWIR imagers is described by a number of parameters that are to be measured using MS test system. Test range can vary from infinity focusing combined with resolution test to measurement series of parameters: resolution, MRC, MTF, and FOV. List of measured parameters can be expanded too.

Test range of VIS-SWIR imagers is determined by two factors:

1. Types and number of VIS targets to be delivered;
2. Number of software modules that support tests.

Detail description of codes used in column F is presented below:

- **F1.** No VIS-SWIR imagers tests;
- **F2.** VIS targets: one positive 100% contrast USAF1951 target; no software support;
- **F3.** VIS targets: edge target, dot-cross target. Software test modules: as in F2 but additionally TAS-V program (MTF, FOV modules) are delivered;
- **F4.** VIS targets: Set of five variable positive contrast USAF1951 targets and software: MC Viewer program.

G Laser boresight tests

MS systems offer two alternative methods to carry out boresight of lasers relative to imagers (checking angle between laser beam and LOS of imager):

1. Tests at low collimator protection mode (LCP mode);
2. Tests at high collimator protection mode (HCP mode).

Both methods of boresight of lasers are based on a concept to use laser sensing cards located at collimator focal plane that could enable viewing light spot created by shooting laser.

The difference is in methods to protect test system (collimator) when testing high power pulse lasers (long range LRFs/designators emitting pulses of pulse energy in range from about 20mJ up to 200mJ).

In detail, Inframet uses two methods to enable boresight laser to imagers:

- **G1.** No Laser boresight tests;
- **G2.** LSC laser sensing card located at collimator typical focal plane (inserted to MRW rotary wheel) to enable laser viewing and AO set of optical attenuators located at collimator output (position regulated using AH holder);
- **G3.** LSC laser sensing card located at secondary focal plane of dual focus collimator (inserted to card pocket).

The G2 method is a solution used by typical systems offered on market. It works fine on condition that the user properly positioned AO optical attenuator opposite laser of tested EO system. However, if AO optical attenuator only partially attenuate laser beam or even worse does not block it at all (user forgot to use it) then high power pulsed laser can damaged secondary flat mirror hit by concentrated lased beam of irradiance over threshold of irradiance density of typical metallic coatings used as mirror coating.

The G3 method is based on idea to use modified collimator of removable secondary mirror having two focal planes (dual focus collimator). in this case is still recommended to use AO attenuators in case of ultra high power lasers but no damage occurs to collimator secondary mirror even if user forgets to use attenuators. This solution is much more costly (modification of collimator) but is much more convenient for users testing long range monopulse LRFs/designators.

In general for testing Laser range finders with energy density equal and higher than 0,4J/cm2 it is recommended to use G3 method.

Attention: the G3 method is not needed when testing multi pulse LRFs due to low pulse energy of transmitters of such laser range finders.

H Laser radiometric/ temporal tests

MS systems offer measurement of radiometric/temporal parameter of lasers using three methods:

- **H1.** No Laser radiometric / temporal tests;
- **H2.** COE pulse energy/COP power meters located at collimator output opposite tested laser (work at low and high collimator protection mode);
- **H3.** COPO integrated meter of pulse energy/power located at collimator secondary focal plane (work at HCM);
- **H4.** OSA optical signal analyzer located at collimator secondary focal plane (work at HCM) capable to measure pulse energy, pulse peak power, mean power, PRF, pulse width, missing pulses.

Method H3 is more convenient than H2 because no manual positioning of meters is needed. Method H4 offers wider test capabilities (more parameters can be measured).

I Laser spot tests

MS systems enable measurement of two-dimensional intensity profile of laser beam at collimator focal plane (infinity plane) and calculation of divergence angle of tested laser using LSR10 laser profilometer. It can be treated as ultra high dynamic VIS-SWIR camera.

I1. No laser spot tests;
I2. LSR10 is delivered (work at HCM).

J LRF specific tests

Transmitters of LRFs can be tested as typical pulsed lasers (see Column H). This section refer to LRF specific tests: 1)variable distance range (checking what range of distances that can be measured using LRF), 2)distance accuracy (error of distance measurement).

LRF tests can be made using two methods:

J1. No LRF specific tests;
J2. Probes of LMOB system located at collimator output plane opposite tested laser;
J3. LOPG pulse generator located at collimator secondary focal plane (work at HCM).

The J3 method is more convenient for use as no precision positioning of laser probes is needed.

Attention: more expanded tests (measurement of ER, receiver sensitivity, operational range) can be done using specialized stations like LUNI, LTE, L64.

7 Exemplary versions

MS can be configured into myriads of versions. Here three popular versions:

1. MS15120-44-8-12-23-22-21-11 – version for basic testing small gimbals for drones (thermal imager, VIS camera, LRF);
2. MS25200-75-8-12-24-24-11-11 – version for testing portable multi imaging binoculars (thermal imager combined with VIS-NIR camera or SWIR imager);
3. MS40240-44-22-23-24-24-34-23 – version for testing expanded testing long range multi imaging/laser systems (large gimbals) built from the following blocks: thermal imagers (optionally two thermal imagers), color VIS camera for day applications, LLLTV camera for night applications, SWIR imager, mono-pulse/or multipulse LRF, laser designator, and laser pointer.

8 Optional solutions

Inframet can deliver also a series of optional support blocks that can significantly increase test capabilities of MS systems;

1. Variable target distance;
2. Set of CEB collimator expander blocks;
3. BORIM autocollimator;
4. IL collimator illuminator;
5. AT optical table;
6. Angular stages.

8.1 Variable target distance

Collimators are typically used when the wheel with a set of targets is located at collimator focal plane. in such a case the collimator project image of a target located in so called optical infinity. Tested imager shall generate sharp image only when it focus is at infinity (long distance).

However, Inframet can modify CDT collimator and exchange typical MRW rotary wheel for a FRW focusing rotary wheel that can move targets along collimator optical axis (movement range about 20 mm) and vary distance perceived by tested imagers. Minimal simulated distance depends on focal length of the collimator and is presented in Table .

Table 4. Minimal simulated distance for collimators of different focal lengths

Collimator focal length [cm]	100	120	150	160	200	240	300	350	400	500	600
Minimal distance [m]	50	75	100	125	200	300	400	600	800	1200	1800

Variable distance simulation is useful to check focusing mechanism of imagers with optics of long focal length (over about 100cm). It can be also very useful when testing space imagers due to ability to simulate focus change due to non vacuum conditions or to correct minor collimator refocusing after shipment.

However, there are also limitations of regulation of distance to simulated target by refocusing of collimator:

1. Collimator refocusing cannot change distance to targets perceived by tested laser range finders;
2. Short/medium range imagers having optics of short/medium focal length perceive even minimal distance simulated by refocused collimator as near infinity;
3. Boresight of laser/imagers should be carried out at simulated infinity distance even if the system is intended for work at shorted distances (say 1km).

Therefore this variable distance simulation is truly needed only in case of testing long/ultra long distance imagers.

8.2 Set of CEB expanders

It is preferable situation when collimator aperture is bigger than minimal circle that overlaps optics of all sensor of multi-imaging/laser system to be tested. This condition is relatively easy to fulfill up to about 300mm. Prices of systems based on bigger collimators rise very quickly. Further on, there is practically on market no collimators of aperture bigger than 600mm in situation when distance between imagers/lasers of some pan-tilt two arm systems can be as high as 1000mm. in such a situation Inframet has invented a CEB collimator expanded block to support boresight of such huge multi sensor systems. It is a kind of infrared periscope that increases apparent collimator aperture.

The set is built from 3 expanders: 1) CEB200 expander (apparent aperture increase by 200mm), 2) CEB400 expander (apparent aperture increase by 400mm), 3) CEB600 expanded (apparent aperture increase by 600mm).

Attention: off axis collimator of aperture at least 350mm is to be used as base collimator.

Set of CEB expanders is much cheaper than bigger collimators but there are also some limitation:

1. It can be used to expand apparent aperture of collimator only in one direction (typically horizontal);
2. Boresight accuracy is worse (estimated at 0.2 mrad level) comparing to method of a single ultra large collimator (angular size of pixel);
3. CEB can be used only during boresight tests. It cannot be used for measurement of performance parameters of imagers like MRTD, MTF, MRC.

Therefore use of test system based on big collimator is a recommended but more costly solution.

8.3 BORIM autocollimator

BORIM boresight autocollimator enables aligning of optical axis (LOS) of imager (thermal imager or VIS-NIR camera) with reference front wall of the imager (axis is perpendicular to the front wall). It is achieved using special ABT target located inside the collimator that emits laser beam to be reflected by small mirror attached to imager reference flat wall. It should be noted that such boresight of LOS of imager to a reference mechanical plane is needed only in case of special thermal sights having such reference wall (example Catherine from Thales).

8.4 IL collimator illuminator

IL collimator illuminator enables to check if tested system is properly positioned relative to collimator of test system. in detail, collimator aperture should overlap optics of all imaging/laser systems. The aim is achieved by emission of visible optical beam by the IL illuminator that that illuminates tested multi-sensor system. It is easy to check if all optics of test system is illuminated to assure that tested system is properly positioned relative to collimator.

8.5 AT optical table

AT optical table is used as a platform for both tested system and test system. It can be delivered in many versions depending on its size and anti-vibration properties (rubber attenuators, air pressure attenuators, QZS attenuators). It should be emphasized that optical table is of crucial importance when testing imager of high Nyquist frequency (over about 50lp/mrad). Details about at tables: https://www.inframet.com/optical_tables.htm

8.6 Angular stages

Some multi imaging/laser systems (gimbal type or pan tilt type) has internal regulation of its angular position relative to collimator. However, other two types (box type or binocular type) need of its angular position relative to collimator axis. Therefore Inframet offers a series of manual/motorized angular stages to support this task. https://www.inframet.com/positioning_stages.htm

9 Special test conditions

Typical MS systems are optimized to work at typical laboratory conditions: ambient temperature in range from about 10C to about 30C, typical air pressure conditions. However, MS systems can be optionally delivered in versions capable to work at:

1. Temperature chamber;
2. Clean room;
3. Vacuum chamber.

Please add following abbreviations to system code: TC, CR, VC. However, please note that these are customized test systems and detail information on work conditions is expected before order is accepted.

10 Comparison to specialized test systems

MS systems in more advanced versions are near universal systems capable to test wide range electro-optical imaging/laser systems. However, basically it is a system optimized for testing multi imaging/laser systems and specialized test station are recommended to test stand alone imagers or laser systems.

Table 5. Advantages of specialized test systems over MS systems

EO system to be tested	Code of specialized system	Advantage
Laser range finders / designators	LUNI, LTE	Ability to measure additionally: extinction ratio ER, receiver sensitivity, operational range, boresight receiver-transmitter
Thermal Imagers	DT	More expanded test range including testing thermal camera cores
VIS-NIR cameras	TVT	Ability to use more advanced light sources and to carry out tests of VIS-NIR cameras using variable spectrum, variable intensity test
SWIR imagers	ST	Ability of precise radiometric calibration of light sources, tests of camera cores
Fused imagers	FUDIT	Contrast regulation of targets of interest in both spectral band

11 Comparison to previous coding of MS system

New coding of MS systems presented in previous section has been introduced to be valid since 2025 year to replace previous one used for last decade. New code is more detail and present additional information:

1. Collimator focal length;
2. Collimator FOV;
3. Size of target plates;
4. Maximal image Nyquist frequency (collimator grade).

There are also some changes in form of description of test capabilities:

1. Unified test range of VIS-NIR;
2. Test capabilities of lasers presented in form of three groups.

12 Summary

1. MS system is one of most sophisticated Inframet test systems capable to test almost all electro-optical imaging/laser systems present market;
2. MS test system can be easily configured by potential user to suit for his applications by adding/removing modules;
3. If you have problems to choose proper versions of MS test system using proposed code please fill questionnaire and Inframet staff shall propose an optimal version. Problem to choose proper version is natural – the reason is complexity of testing multi-sensor systems;
4. This data sheet present a list of typical versions of MS test system. Inframet can deliver customized versions;
5. Please contact Inframet if you have any questions. We are happy to serve you and work had to keep our status as leader in field of apparatus for testing electro-optical surveillance systems.

Version 7.1

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