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Testing of military optoelectronic systems

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Military optoelectronic systems proved their great usefulness at night or poor atmospheric conditions during recent conflicts. However, to assure high effectiveness of these sophisticated systems, they must be regularly tested. Due to secrecy of some military optoelectronic systems, limited availability of military standards, and numerous but inconsistent literature there is significant confusion in the area of military optoelectronic metrology. A review of typical testing methods of the three basic groups of optoelectronic systems (missiles guided using optoelectronic methods, optoelectronic imaging systems, and optoelectronic countermeasures) used in modern military armament is presented in this paper.

Keywords: infrared systems, forward-looking infrared, instrumentation, measurement and metrology.

1. Introduction

The most important groups of optoelectronic technology in military armament are: missiles guided using optoelectronic methods, optoelectronic imaging systems [thermal imaging systems, image intensifiers, low light level television (LLLTV) cameras, TV cameras] and the optoelectronic countermeasures [smoke screens, camouflage paints and nets infrared, (IR) flares, decoys, the stealth techniques, jamming systems, and warning systems]. The role of optoelectronic technology in military armament rapidly increases now and it is difficult to imagine modern military warfare without this technology.

The missiles guided using the optoelectronic methods represent about half of all the short-range air-to-air or air-to-ground missiles. They are majority of all the short-range ground-to-air or sea-to-air missiles and their number increases in the groups of anti-tank missiles or long-range missiles. Thermal imaging cameras for night observation and TV cameras for day observation are becoming a preferred solution for military surveillance for tanks, armoured vehicles, helicopters, aircraft, and ships. Image intensifiers are still used in high numbers by infantry or in other applications requiring small size, light devices of low price. LLLTV cameras are sometimes used as low-cost alternative of thermal imaging cameras in airborne applications. Finally, optoelectronic countermeasures like the smoke screens, camouflage paints and nets, IR flares, decoys, stealth techniques, jamming systems, and warning systems can significantly reduce effectiveness of the above mentioned systems. Therefore many of countermeasures are used in the army, air force, and navy.

It is necessary to carry out periodical testing of all types of optoelectronic systems described earlier in order to avoid serious military and economic consequences. Numerous military standards, some of them secret, are used that precise determined parameters to be tested and testing methods to be used [1–14]. A lot of papers on testing of the above-mentioned systems are known, although mostly of them on testing of thermal imaging systems [15–22]. However, still it is significant confusion in this area due to secrecy of some parameters and testing methods, differences in recommendations of different military standards or papers.

A review of the testing methods of three basic groups of optoelectronics systems used in modern military armament; the missiles guided using optoelectronics methods, the optoelectronic imaging systems, and the optoelectronic countermeasures, is presented in this paper. The IR simulators used for testing the passively and actively guided missiles are described in Section 2; the measuring sets for testing thermal imaging systems in Section 3; the measuring sets for testing image intensifiers, TV cameras, LLLTV cameras in Section 4; and finally the testing methods of optoelectronic countermeasures are discussed in Section 5. After that the recent trends in the measuring sets used for testing of the optoelectronic armament are presented in Section 6.

2. Testing of missiles with optoelectronic heads

Five optoelectronic methods are commonly used for guiding missiles: reticle method, image analysis, target irradiation by laser radiation, method of laser beam, and fibre line method. Combinations of these methods are used, too.

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Reticle method employs circular optical plate with adjacent transparent and non-transparent parts called the reticle that is fixed at the image plane of the imaging optics of the head of the missile. A single IR detector of the size a bit larger than the reticle is placed just behind the reticle. The location of the point image of the target on the reticle plate changes, even when the target does not change its position, due to rotation of the reticle or rotation of the imaging optics. Therefore radiation emitted by the target generates electrical pulses at the detector output. Pulse duration and phase of these pulses give information about angular position of the target (Fig. 1).

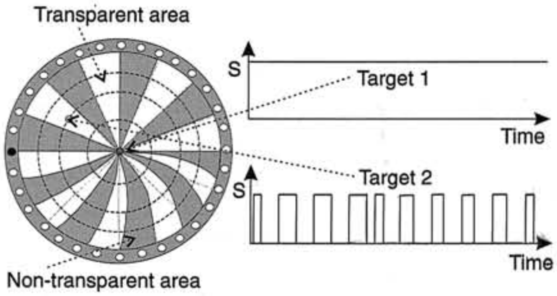

Fig. 1. Exemplary reticle and the signal generated at detector output by a few targets of different location.

Despite simplicity of this method and application of a single detector only, the reticle method is a very effective way of guiding missiles when the target is on a uniform background. So, this method is currently used for many air-to-air, ground-to-air, or sea-to-air short-range missiles. However, effectiveness of the reticle method decreases significantly for targets on non-uniform background like typical ground military targets.

Missiles employing the method of image analysis have a TV camera or a thermal camera in their optoelectronic head. Location of a target is determined from analysis of the image generated by a TV camera or thermal camera. These missiles are not limited comparing the missiles employing the reticle method and can attack targets located in the non-uniform background. Thus, some of the air-to-ground missiles use this method to attack and destroy ground targets; particularly large non-movable targets like bridges, bunkers, buildings, etc. However, other significant technical limitations of this method exist. First, the missiles using the TV cameras can operate only in the day light conditions. Second, it is very difficult to design the thermal camera for high-speed missiles. Such a camera must be of small size, very fast operating, reliable, ready to withstand harsh environmental requirements, and of low manufacturing costs. Therefore, the imaging missiles using thermal cameras in their optical head are still at a development stage. However, they offer great potential capabilities and their number can rapidly increase with introduction of new generation of uncooled arrays of infrared detectors.

Missiles employing the irradiated target method are homing on the target irradiated by a laser illuminator cooperating with the missile using the radiation pulses on emitted by the laser and reflected by the target. The method enables us very accurate location of small targets in a highly non-uniform background and is particularly well-suited for air-to-ground missiles. However, it is an active method and employing warning systems or other countermeasures can significantly reduce its effectiveness.

Missiles employing the method of the laser beam are kept on their flight to the target within the beam emitted by the laser illuminator that irradiates the target. Laser radiation that gives information about the location of the target comes directly from the illuminator to the sensors at the back of the missile, not after the reflection by the target as in the previous method. Therefore low-power illuminators can be used here and effectiveness of the warning systems is reduced.

Missiles employing the fibre line method typically are kept on their flight to the target by the control centre operator. Requirement of direct sight of the target limits significantly range of these missiles. Missiles of this type are used typically against tanks or other armoured vehicles. Currently, new generations of fibre line missiles are available commercially and they do not require direct sight as they use TV cameras or thermal cameras in their heads. It significantly increases their range.

The maximum range at which the target can be detected is a critical parameter of any missile. Due to decreasing the detector responsivity with time, non-aligning of the optics, and changes within the electronic blocks, this range can decrease with time. Maximum detection range is typically tested periodically every 1–2 years using the measuring set presented in Fig. 2.

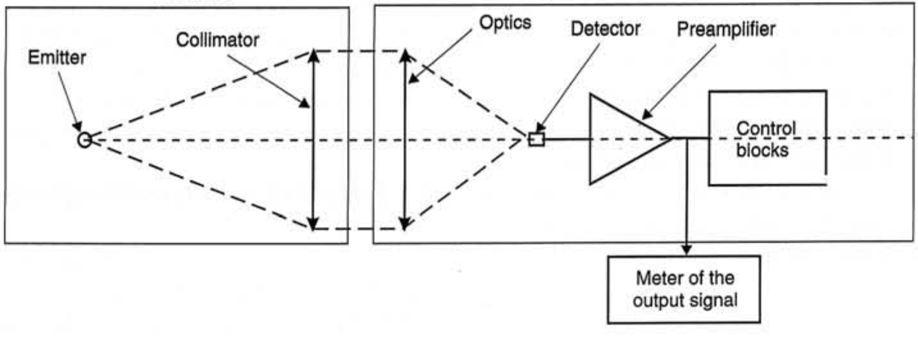

Fig. 2. Simplified scheme of the measuring set for testing of the detection range of the missiles guided using optoelectronic methods.

The measuring sets used for testing the missile range are typically called simulators. Simulators imitate the presence of a single target in, so-called, "optical infinity" for the tested missile. A simulator consists of two basic blocks: infrared source and collimator. The angular position of the simulator changes according to a certain algorithm for not moving tested missile; or vice versa. Radiation emitted by the simulator coming to the optical head of the missile generates a signal at the control point of the electrical channel of the missile. If this signal does not fulfil the criteria determined by the missile's manufacturer, it means that the detection range is below the required value and the missile fails the test.

Some differences are observed between simulators used for testing various missiles. For guided missiles using the reticle method (or the image analysis method), the aim of the simulator is to imitate presence of targets like aircraft or helicopters emitting their own radiation. Simulators used for testing of such missile use typically continuously emitting sources of radiation like small bulbs. These bulbs are tungsten filament lamps fixed within special envelopes transmitting radiation in the middle-infrared range 1–6 µm. Due to high costs of large size infrared refractive optics, the collimators of these simulators are usually made using reflective optics. The Cassegraine optical objective is the preferred solution for these collimators. Exemplary static simulator from this group is presented in Fig. 3.

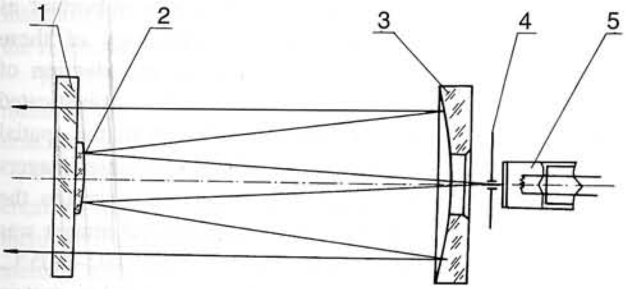

Fig. 3. Optical scheme of the Soviet made KN-U simulator used for testing of air-to-air missiles guided using the reticle method: 1 – optical filter; 2 – small spherical mirror; 3 – large spherical mirror; 4 – baffle; and 5 – infrared emitter.

For guided missiles using the irradiated target method, the aim of the simulator is to imitate radiation emitted by the illuminator (the laser) and reflected by the irradiated target. Simulators used for testing the guided missiles using the irradiated target method emit radiation in form of pulses of the specified wavelength, peak power, frequency, pulse duration, and phase.

Most lasers illuminators used for target irradiation emit radiation at the wavelength shorter than 1.8 µm. Optical materials like BK7, quartz, or others refractive optical materials transmit well in this spectral range. Therefore refractive optics is typically used in these simulators in contrast to the earlier presented reflective type simulators. The radiation sources are required to emit short time pulses of duration, e.g., equal to 50 ns. It is not possible to achieve such short time pulses using the earlier mentioned IR lamps due to their high time inertia. Special LEDs emitting at the required wavelengths are typically used as sources of radiation for this type of simulators. The optical scheme of an exemplary simulator for testing of the guided missiles using irradiated target method is shown in Fig. 4.

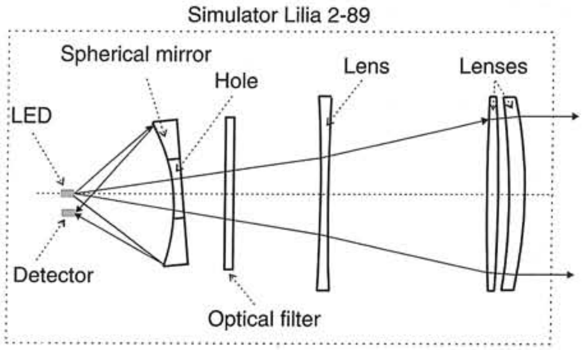

Fig. 4. The optical scheme of the Lilia 2-89 simulator used for testing of an air-to-ground missile guided using the irradiated target method.

The LED, used as a radiation source for the Lilia 2-89 simulator, emits the pulses in a few times wider spectral band than the spectral band of the target illuminator. Therefore the optical band pass filter is used to narrow the spectral band of the beam emitted by the Lilia 2-89 simulator. A spherical mirror with a hole is used to create an image of the emitting LED on the detector that generates signals used for control of power, frequency, and pulse duration of the emitted pulses.

Missiles are periodically tested with the described simulators during their whole utility period that can last sometimes up to 30 or more years. The missile parameters can change significantly beyond the acceptable specifications during such a long time. When the parameters not fulfil the requirements, the missiles are excluded from the operational readiness. As we can see, the decisions of serious military and economic consequences are made on the basis of simulator measurements. Thus, the simulators must be also tested periodically in order to avoid the situation when fully operational missile is treated as faulty or vice versa.

Three parameters are measured during the static simulators testing: power of radiation within the specified spectral band, divergence angle of the emitted beam, and uniformity of irradiance distribution within the beam. More parameters are measured for the pulse simulators: centre and width of a spectral band, peak power, frequency, and pulse duration of the emitted radiation.

3. Testing of thermal imaging systems

The minimum resolvable temperature difference (MRTD) is currently considered as the most important parameter of thermal imaging systems [1]. MRTD enables us to estimate probability of detection, recognition, and identification of military targets knowing MRTD of the evaluated thermal camera [23,24]. Military standards determining testing the thermal imaging systems usually specify that MRTD values for a set of spatial frequencies of the tested imager must be lower than certain values if the imager is to pass the test [3–5].

The MRTD is a subjective parameter that describes ability of the imager-human system for detection of low contrast details of the tested object. It is a function of a minimum temperature difference between the bars of the standard 4-bar target and the background required to resolve the thermal image of the bars by an observer versus spatial frequency of the target. The measurement results of a typical military thermal camera for airborne surveillance are shown in Fig. 5.

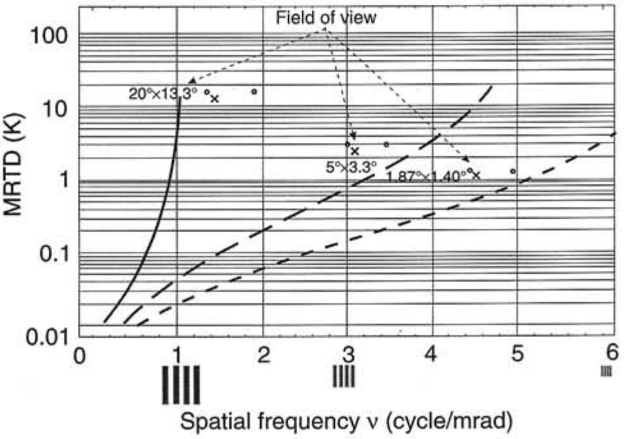

Fig. 5. MRTD of an example military thermal camera used in airborne surveillance.

A diagram of the measuring set for testing MRTD of thermal camera imagers is presented in Fig. 6. The setup consists of five main items: differential blackbody, set of target plates mounted in a rotary wheel inside an enclosure, IR collimator, and optical table. The measurement procedure is described below.

A set of the standard 4-bar targets of different spatial frequencies is fixed to the rotary wheel placed at the focal length of the collimator. One of the targets is within the field of view of the IR collimator. The differential blackbody is close behind this target. The luminance distribution on the target surface and the blackbody is imaged onto the monitor of a thermally imaging system where the image is viewed by an observer. The temperature difference between the bars (the blackbody) and their conjugates (the target) increases incrementally until the observer can distinguish the 4-bar target. This critical temperature difference is the MRTD. Measurements of the MRTD are typically made for both positive and negative temperature differences. The observer has unlimited time to make a measurement, and is allowed to optimise his distance to the screen, the electronic zoom mechanism of the tested thermal imager. The influence of the phasing effects on the quality of the thermal image of the 4-bar targets is minimised by precise rotation of the imager within the angle close to the field of view (FOV) of the imager.

The measurement results of the MRTD can vary from test-to-test and from observer-to-observer. An MRTD variability as high as 50% from laboratory-to-laboratory and 20% variability within one laboratory were reported [17]. However, it seems that apart from the observer variability, non-standardised equipment and measurement methodology are other significant sources of the dispersion of measurement results. The problem of equipment for testing of commercial thermal imagers is particularly important as great progress has been made in technology of these imagers during the last decade. Due to introduction of two-dimensional matrixes of detectors and sophisticated electronics and optics of low F-number, both the spatial resolution and the temperature resolution of these imagers have been significantly improved. About ten years ago, the temperature resolution of a typical commercial imager was about 0.1–0.2°C, now it diminishes to about 0.02–0.05°C. Similarly, spatial resolution of the present-day matrix

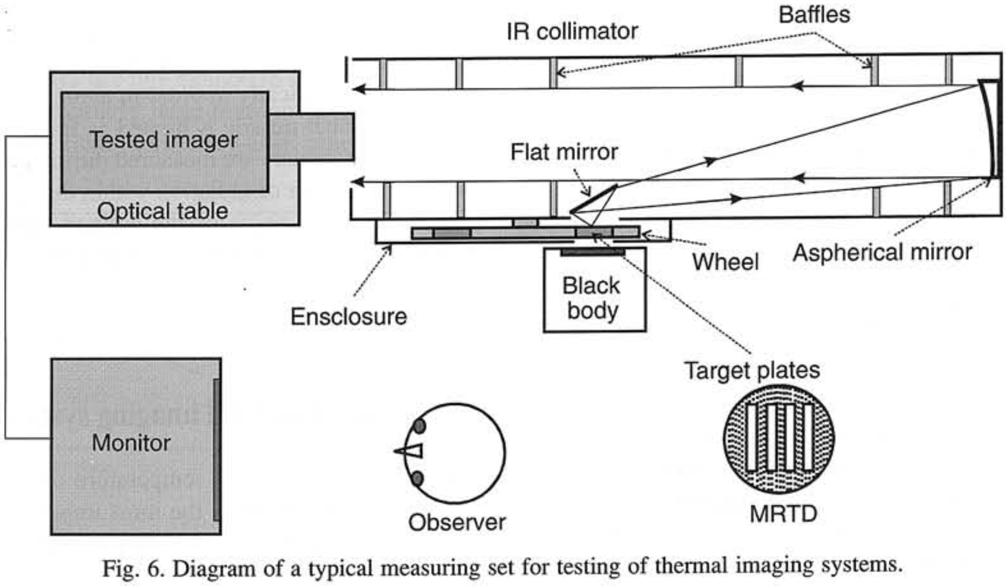

Fig. 6. Diagram of a typical measuring set for testing of thermal imaging systems.

imagers is about two times better than the resolution of the older scanning systems. These improvements significantly increased requirements for the elements of laboratory setup and measuring procedure of the MRTD necessary to produce reliable results. Detail requirements on the measuring sets for testing the modern thermal imaging systems are presented in Ref. 25.

4. Testing of image intensifiers, TV cameras, LLLTV cameras

The spectral range of military image intensifiers, TV cameras, and LLLTV cameras is from about 0.4 μm to about 1 μm. This spectral range overlaps the visible range and, as consequence, some of the testing methods of typical visible optics like monoculars, binoculars, optical sights, telescopes can be used also to test image intensifiers, TV cameras, and LLLTV cameras.

The resolution is the most important parameter of the systems discussed here. There can be found in literature many definitions of resolution of optoelectronic systems [16]. However, resolution of the above mentioned systems is typically defined in military standards as maximal spatial frequency of a standard line pattern that can be revolved by an observer at a certain illuminance level and the target contrast [7,8]. This definition was chosen because it is possible to estimate probability of detection, recognition, and identification of military targets with the evaluated image intensifier, TV camera, or LLLTV camera on the basis of the resolution defined in the way presented earlier.

The USAF 1951 target is typically used for measurements of resolution of military image intensifiers, TV cameras, and LLLTV cameras (Fig. 7).

The target consists of a series of elements (patterns) decreasing in size, with a range sufficient to cover requirements of the tested systems. Each group consists of six elements, which are progressively smaller. The elements within a group are numbered from 1 to 6. Odd-numbered groups appear contiguously, 1 through 6, at the upper right corner. The first element of even-numbered groups is at the lower right, with the remaining five elements, 2 through 6, at the left. Each even-odd pair makes up a layer, with the next smaller even-odd pair near the centre. The standard target element consists of two patterns (two sets of lines) at right angles to each other. Each pattern consists of three lines separated by the spaces of equal width. Each line is five times as long as it is wide.

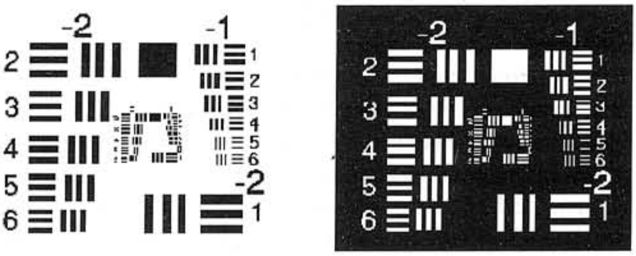

Fig. 7. The USAF 1951 standard target (in positive and negative versions).

Measuring sets for testing image intensifiers, TV cameras, and LLLTV cameras consist usually of three basic blocks: collimator, the USAF 1951 target, and illuminator (Fig. 8).

Illuminator should illuminate uniformly the USAF 1951 target that is fixed at the focal plane of the collimator. Then, the collimator projects image of the target in, so-called "optical infinity" to the tested device. Resolution is determined as the maximal spatial frequency of the USAF 1951 target that can be revolved by an observer. The observer can regulate the level of illumination of the target during measurements. In order to reduce the effect of limited repeatability of human eyes, at least 3 observers are used during these measurements and the results are averaged.

The influence of blocks of the measuring set on the measurement results of the resolution must be negligible.

In order to achieve this aim the following detail requirements should be fulfilled:

- resolution of the collimator should be at least 5 times better than the resolution of the tested device,
- aperture of the collimator should be at least 10% larger than the aperture of the tested device,
- collimator should be coated inside with low reflectivity paint, and be equipped with baffles covered with the same paint that prevents radiation emitted by sources outside the collimator from reaching the target plate,
- target USAF 1951 should be illuminated with uniformity better than 5%,
- illuminator block should allow users to regulate illuminance of the target within the illuminance range the tested device is designed to work,
- control of the colour temperature of the source of the illuminator within the range from 2700 K to 3300 K (military standards typically require to use an illuminating source of colour temperature within this range) should be possible.

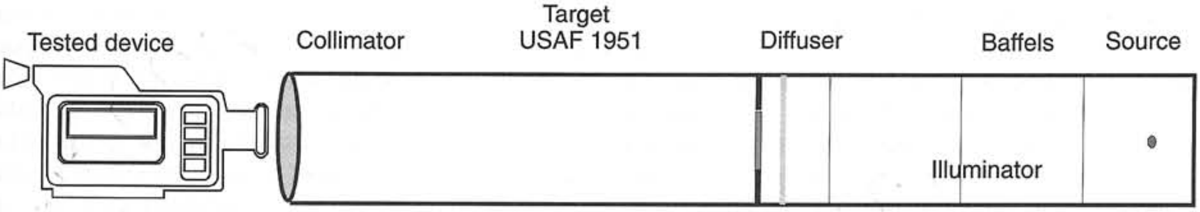

Fig. 8. Optical diagram of a measuring set for testing of image intensifiers, TV cameras, and LLLTV cameras.

5. Testing of countermeasures

Optoelectronic countermeasures are the part of electronic warfare that attempts to eliminate or minimise an enemy's ability to inflict damage by denying the enemy use of the optical spectrum. This aim can be achieved by a vast range of actions: blocking the visibility of the target by smoke screens; eliminating characteristic target signatures used by enemy to recognise the target or to home in on the target by use of the camouflage paints, nets or by making changes in the target design using the, so called, stealth techniques; by mimicking target signatures at some distance from the target by means of target flares and decoys; jamming the enemy's sensors by emitting high power optical radiation into direction of the attacking missile or emitting pulses of low power but of proper combination of frequency, time width and phase; or finally by using the warning systems.

Parameters of the optoelectronic countermeasures are often classified. Therefore it is difficult to discuss in details the testing methods of these systems in such a situation and only some general guidelines will be presented below. Smoke generators should limit the atmospheric transmittance in the optical range. It is relatively easy to achieve high suppression of the transmitted radiation in the visible range, however, the task is much more difficult with the infrared radiation in the spectral bands of the thermal imaging systems; 3–5 μm or 8–12 μm. However, a significant progress has been recently made in the smoke screens. There are currently commercially available pyrotechnic materials generating smokes that attenuate thermal radiation emitted by the protected target in the 3–12 μm band and at the same time they emit their own thermal radiation and can significantly decrease the contrast between protected target and background.

Different methods are used to test the above-discussed smoke screens. Sometimes the transmittance versus wavelength and the spectral distribution of the emitted radiation are measured at the laboratory conditions. Another possibility is to measure the mentioned earlier parameters at field conditions. However, it seems that the most popular are the tests of smoke effectiveness with a standard target, a thermal imager and the smoke screen between them. If the target disappears from the screen of the thermal imager for the required period of time or is at least significantly distorted then the smoke passes the test.

It has been known for centuries that by painting the target in a special pattern using green, brown or grey paints is possible to decrease the contrast target-background and to reduce probability of detection and recognition by enemy eyes. Modern camouflage paints and nets do generally the same. However, they are intended to decrease the target-background contrast not only in the visible range but also in the infrared or microwave ranges. Because of the extended spectral range, the requirements for the modern camouflage nets differ significantly from the requirements on the old ones. Not only the reflectance distribution but also the temperature and emissivity distributions on a surface of the protected target such be similar to the reflectance, temperature and emissivity distributions of the background. The tests of such nets can be done by measurements of the reflectance versus wavelength, and the temperature and emissivity distributions in laboratory conditions. However, it seems that more often the tests are carried out in field conditions using a few standard targets protected by the tested camouflage equipment and different optoelectronic imaging systems like thermal cameras, image intensifiers, and TV cameras. If, after using the nets, the image of the target disappears or is significantly distorted then the camouflage net passes the test.

Camouflage nets are rather suitable for non-movable military targets when the background is known and does not change. The technique of mimicking target signatures, at some distance from the target, by means of target flares or decoys is popular for protecting movable targets like aircraft, helicopters, ships and ground vehicles. The limits between flares and decoys is fluid and generally a flare can be treated as a simple decoy. The decoy in this simplest form is a small-size pyrotechnic material that after reaction reaches high temperature of over 2000°C and emits high power IR radiation. This type of decoy was a very effective countermeasure against old generation missiles homing on the heat source like aircraft of helicopters. However, the spectrum of radiation of aircraft or helicopters significantly differ from the spectrum of radiation of typical infrared flares and modern missiles employing detection in two spectral bands can reject the flares as false targets (Fig. 9).

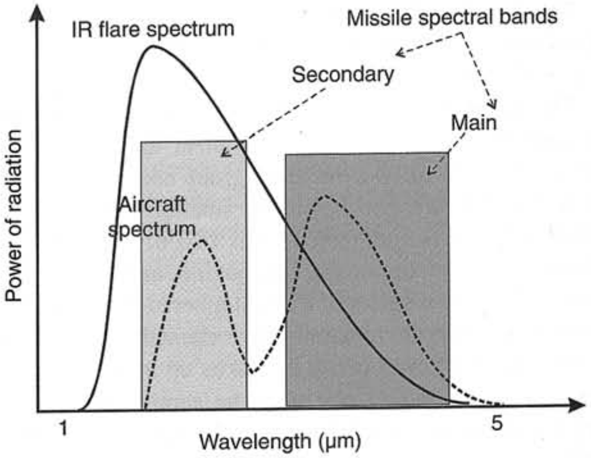

Fig. 9. Simplified spectrum of a IR flare, a aircraft, and the location of spectral band of modern two-band missile.

Other techniques like analysis of trajectory of decoy movement or the size criterion can be used for rejection of the decoy, too. Therefore sophisticated decoys of spectrum and size more resembling the parameters of the protected airborne or naval target are used currently. Sophisticated 3-dimensional decoys for the protection of ground targets of size, shape, spectrum of emitted and reflected radiation, etc. very similar to the protected targets are also available commercially.

Testing methods of the decoys depend significantly on type and application of the decoy. For small size decoys, like flares, the power of emitted radiation versus wavelength and time is typically measured. Measurements of power emitted within a specified spectral band are sometimes carried out, too. For sophisticated 3D decoys, the images of decoy and the protected target are recorded in different spectral bands and the comparisons are carried out in order to check whether the decoy fully imitates the protected target; or at least if the decoy resembles the targets in all the spectral bands.

Flares are small size sources of IR radiation. As discussed earlier, they can be used for protection of aircraft or helicopters by mimicking the protected targets. However, if they are of sufficient power and are used in high number, they can jam the sensors of the attacking missile. They can also create a temporary screen covering the protected target against optoelectronic imaging systems. High power bulbs or lasers can jam the attacking missiles in the same way by saturation of the detection system of the missile. Next, the laser illuminators can be used to destroy the sight of human operators of imaging systems, too.

The aim of jamming the sensors of the attacking missiles can be achieved also by emitting pulses of low power radiation into the missile direction. If a proper combination of spectrum, frequency, duration of the pulses is used, the attacking missile will change its flight path away from the protected target. However, the effectiveness of this technique is based on the knowledge on the precise values of the above mentioned parameters. Next, this method can be used only against the missiles homing using the reticle method or the illuminated target method.

In the first group of the jamming systems, the power of emitted radiation is the most important parameter. Thus, directional and time characteristics of radiation emitted in a specified spectral band are measured. For the low power jamming systems the spectrum, frequency, pulse duration, and power of the pulses of the emitted radiation are measured.

The warning systems enhance survivability of the protected target by providing an early warning to the crew of the impending threat. An ideal laser warning systems should detect the pulses of laser radiation of any wavelength, low powers, any frequency, any time width, and coming from any direction. The warning system should also indicate accurately and immediately the direction of the coming radiation. It is desirable if the warning system could determine the wavelength and other parameters of the received radiation, too. The parameters of the laser warning systems that are measured during testing can vary according to their specifications. However, it seems that the following parameters: field of detection, spectral band, frequency band, minimal required time of irradiation are typically measured. The parameters give vital information about real capability of the tested warning system as when the source of illumination is outside the detection field, or if the laser emits radiation at wavelength outside the spectral band, or the frequency of radiation is outside the frequency band, or the illumination source emits the pulses of duration shorter than minimal pulse duration, then the illuminated source will not be detected.

6. Recent trends in measuring sets used for optoelectronic armament testing

The simulators presented in Section 2 imitate only a single target and allow only for determination of the range of detection of the tested missiles. The scenes generated by these simulators do not resemble real scenarios and these simulators cannot be used to test behaviour of the missiles in real conditions. Dynamic scene projectors that could project realistic IR scenes can be treated as a new generation of the simulators presented in Section 2. Different technologies like resistive arrays, deformable mirror arrays, mirror membrane devices, liquid crystal light valves, laser writers, laser diode arrays, and CRTs can be used to develop these projectors [26,27]. Also other techniques for providing IR scenes are used that involve the use of silhouette (in some cases textured scenes). All these scene projectors can potentially eliminate the need of extensive and expensive battlefield tests. However, at present, it seems that only the silhouette technology is matured enough to be used in practical applications.

No significant changes can be expected in the near future in the measuring sets for thermal cameras testing. Temperature resolution and spatial resolution of the new generation of thermal cameras constructed with the non-cooled arrays of detectors are not better than the parameters of the older generation of imagers built using the cooled arrays. Therefore the existing measuring sets can be used to test new non-cooled thermal cameras. Higher requirements can be expected only from the improved cooled thermal cameras of higher temperature and spatial resolutions that due to high speed requirements will be still used in some airborne applications. The higher demands for the measuring sets from the latter group can be satisfied by improving temperature resolution, uniformity, and accuracy of the blackbodies. It can be expected that blackbodies of resolution equal to 1 mK will be typically used when the current standard is 10 mK.

More significant changes can be expected in testing procedures. Current standards regulating the measurement of the MRTD [1–5] do not include precise algorithms of measurement or precise requirements for the testing equipment. As a result, high variability of measurement results, as high as 50% from laboratory-to-laboratory, is often met nowadays. Uncertainty of measurements, according to the rules approved by the international metrological organisations [28], is rarely determined. Now, a general trend is observed world-wide to accept, so-called, quality systems, according to the international standards ISO 9001-9004 and the EN 45001-45003, that recommend formalisation of measurement procedures. It can be expected that in the near future the testing procedures of the thermal imagers will be more formalised.

Sensitivity and resolution of a new generation of image intensifiers, TV cameras, and LLLTV cameras are better than the parameters of the older generation devices. However, the changes are not very significant and it seems that currently used measuring sets of scheme presented in Fig. 8 can be used to test them, too.

7. Conclusions

Military optoelectronics represent a vast, rapidly changing part of military technology. It is not possible to present, within one paper, the testing methods of all optoelectronic systems, especially as the testing methods of the most modern systems are secret. Therefore, it must be emphasised that the review of testing methods of military optoelectronic systems is limited to typical systems, and that in case of the systems considered as secret ones, only some general guidelines were presented. Nevertheless, this review gives a glimpse on an increasing role of optoelectronic metrology in military applications.

References

1. STANAG No. 4349, *Measurement of the Minimum Resolvable Temperature Difference (MRTD) of Thermal Cameras.*
2. MIL-STD-1859, *Thermal Imaging Devices, Performance Parameters.*
3. MIL-T-49381 Test Set, *Thermal Sight TS-3681/VSG*, USAERADCOM, 1980.
4. MIL-I-24698(SH), *Infrared Thermal Imaging Systems*, Department of Defence USA, 1988.
5. MIL-STB- 2194, *Infrared Thermal Imaging Survey*, Procedure for electrical equipment, Department of Defence USA, 1992.
6. MIL-T-23592, *Test Set, Infrared Detecting Set AN/AAM-6*, 1983.
7. MIL STD 1858, *Image Intensifier Assemblies, Performance Parameters*, Department of Defence USA, 1992.
8. MIL-A-49425, *Aviator's night vision imaging system AN/AVS6(V)1*, Department of Defence USA, 1987.
9. MIL-V-49074, *Viewer, Infrared AN/PAS-7*, 1976.
10. MIL-P-2018J, *Paint, Face, Camouflage*, 1989.
11. MIL-T-55420A, *Tactical Imagery Interpretation Facility AN/TSQ 43*, 1989.
12. MIL –C- 53004B, *Camouflage Screening Systems, Modular, Lightweigth, Synthetic, Woodland, Desert and Snow*, 1989.
13. MIL-F-70518 (AR), *Flare, Infrared Tracking, Mark 33 Mod O*, 1984.
14. MIL-T-81784B(AS), *Target Simulator, Infrared SM-630*, 1977.
15. "Electro-optical systems design, analysis and testing," in *The Infrared & Electro-Optical Systems Handbook*, Vol. 4, edited by M.C. Dudzik, SPIE Optical Engineering Press, Bellingham, 1993.
16. G.C. Holst, *Testing and Evaluation of Infrared Imaging Systems*, JCD Publishing Company, Winter Park, 1993.
17. C.W Hoover Jr. and C.M. Webb, "What is MRT? How can I get one?", *Proc. SPIE* **1488**, 280–288 (1991).
18. *The Infrared & Electro-Optical Systems Handbook*, Vol. 4: Electro-Optical Systems Design, Chapt. 4: EO System Performance Prediction, edited by M.C. Dudzik, SPIE Optical Engineering Press, Bellingham, 1993.
19. J.T. Wood, W.J. Bentz, T. Pohle, and H. Hepfer, "Specification of thermal imagers," *Opt. Eng.* **15**, 531–536 (1976).
20. J.T. Wood, "Laboratory bench analysis of thermal imaging systems," *Opt. Eng.* **15**, G193–G197 (1976).
21. A.L. Rodgers, I.B. Fowler, T.K. Garland, J.A. Gould, D.A. James, and W. Roper, *Surveillance and Target Acquisition Systems*, Royal Military College of Science, Shrivenham, 1992.
22. J.M. Lloyd, "Thermal imaging system," Plenum Press, New York, 1975.
23. J.A. Ratches, "Static performance model for thermal imaging systems, *Opt. Eng.* **15**, 525–530 (1976).
24. J.A. Ratches, W.R. Lawson, L.P. Obert, J.M. Swenson, *Night Vision Laboratory Static Performance Model for Thermal Imaging Systems*, USA Electronics Command Report 7043, April 1975, AD/A 011212.
25. K. Chrzanowski, J. Fischer, and W. Wrona, "Testing of thermal imagers for non-destructive thermal testing applications", *ASTM Journal of Testing and Evaluation* **28**, 395–402 (2000).
26. O.M. Williams, "Infrared projector effective blackbody temperature," *Opt. Eng.* **33**, 230–236 (1994).
27. R.G. Driggers, K. Burroughs, and O. Wiliams, "Review of infrared scene projectors technology – 1993," *Opt. Eng.* **33**, 2408–2417 (1994).
28. *Guide to the Expression of Uncertainty in Measurement*, International Organisation for Standarisation-International Electrotechnical Commission-International Organisation of Legal Metrology-International Bureau of Weights and Measures, TAG 4/WG 3 (1993).