



Self Protection of Aircraft versus Resistance of Missile Optic Seekers (CM vs. CCM)

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Abstract:

The paper deals with one of the possibilities to increase surface-to-air homing missiles optical seeker resistance against decoys (dummy targets). First, there is an introduction to contemporary aircraft countermeasures and seeker countermeasures against jamming. In the next part, a method to increase a seeker resistance with utilization of multispectral analyses of a decoys optical radiation is introduced.

Keywords:

Resistance, jam, protection, optic, seeker, multispectral, analyses

1. Introduction

Surface-to-air and air-to-air homing missiles optical seeker resistance against artificial jamming of decoys (chaff, flares) is an important factor which influences combat efficiency and the usage of short range and middle range homing missiles significantly. Producers of homing missiles attempt to increase their resistance continually, because technical assets of artificial jamming used as a fixed wing or rotary wing countermeasures against homing missiles have been developed and improved all the time. Also means of jamming increases constantly. As the result, the closed circuit of homing missiles optical seeker countermeasure development, as well as the defence systems of flying objects counter-countermeasure reaction in the form of technical solution and technology advances appear.

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1.1. Aircraft Countermeasure Basics

Historically first, there were artificial jamming assets in the form of infrared decoys. It is a pyrotechnical device radiating omnidirectionally in the visible ($0.38\div 0.78\ \mu\text{m}$) and especially in the infrared ($3\div 5\ \mu\text{m}$) spectrum. Originally, the purpose for development of those devices was simple, **to match spectral radiation pattern of decoys M_e** with a **spectral sensitivity r_d** of a homing missile seeker photo detector (Fig. 1). The desirable effect was that a decoy radiated a sufficient amount of energy in the range of used photo detector sensitivity. Practically, a decoy – cartridge burns after being fired away and makes significant heat track, which is larger than the heat track of a defended object. A homing missile very often changes its manoeuvre to the decoy, possibly the photo detector is saturated (confused) by a quick heat radiation grow so much that the missile stops the homing process and flies out of the target range.

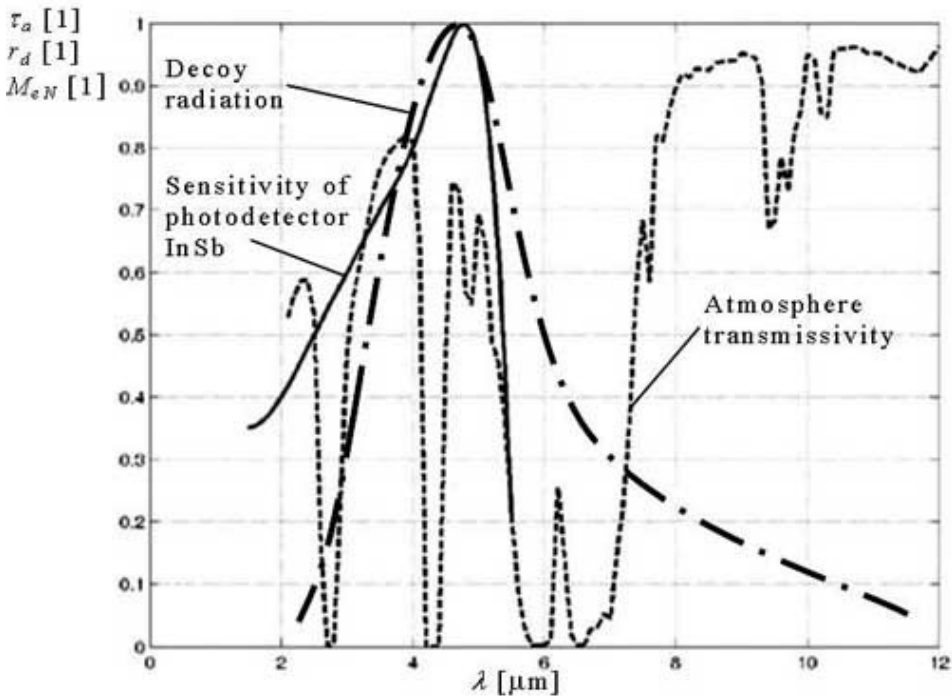


Fig. 1 Example of decoy radiation normalized characteristic M_{eN} ($T = 650\ \text{K}$), spectral sensitivity of photo detector r_d (InSb, $T = 77\ \text{K}$) and atmosphere transmissivity τ_a

Spatial or **energy** characteristics, even spectral anomalies of radiation pattern of concrete aircraft or helicopter was not considered. Also a **way of cartridge ejection** (its movement parameters), that means direction, velocity, time constraints etc., was not optimized according to a jammed homing missile parameters and its separate parts. Effectiveness of simple aircraft countermeasure assets was decreased during a homing missile systems evolution. That is why a complex spectrum of factors had to be taken into account [1].

1.2. Contemporary Aircraft Countermeasures (CM)

Aircraft countermeasures, especially jamming and shielding systems, could be divided into two areas; “already launched (guided) missile” CM and “before aiming the aircraft” CM.

There are two types of assets in the first (“already fired missile” CM) category: active jammers (infrared or radar) and decoys (infrared or radar). A strong evolution process is going on in the area of on-board optical jammers – infrared pulses (eventually radar waves) generators which are theoretically the most effective among the known protection systems (e.g. Russian L166V-11E Ispanka, KT-01 Adros, American ALQ-144, or Russian Astra-V and American AN/ALQ-136) [2]. Infrared decoys are designed with the aim of the spatial characteristics, movement characteristics and spectral characteristics versus protected objects characteristics maximal match. Modern infrared decoys have an optimized ratio of radiation intensity at two or more wave lengths with protected object radiation intensity (see Chapter 3). Another possible way to improve decoys is a programmed change of the burning temperature. The last but not least way to increase aircraft endurance and resistance against “already launched missiles” is fortified armour.

In the field of increasing aircraft protection “before their aiming”, the main evolution trend is in the improvement of aircraft detection systems and illumination indication with an exploitation of active or semi-active homing (**optical – laser and radar warning receivers**: Russian L-140 Otlík, American AN/AVR-2 and Russian L-006 Berjozka, SPO-15 Sirena, L-150 Pastel, American AN/APR-39); and detection and indication systems of launched missiles with passive homing (warning receivers of ultraviolet radiation: Russian L-136 MAK UFM and American AN/AAR-60). The range of L-136 receiver is up to 10 km for Stinger or Strela-2 missiles and 30÷50 km for Sidewinder or R-60 missiles [2]. One of those modern systems is directional (whole circular, semi-spherical or spherical) **detection and indication system of ultraviolet radiation sources**, which is a sign of missile engine fire-up and therefore possible aircraft jeopardy.

General ways to increase an aircraft protection against “before aiming the target” is to decrease temperature, emissivity and radiation surfaces of a protected object [3]. Therefore, **exhaust fumes coolers** are used. The largest sources of infrared radiation are engine exhaust parts. Especially in the case of combat helicopters, special boxes are installed into their exhaust nozzles (Russian EVU, UPTG and American BHO, HIRSS). The principle of those boxes is that the hot exhaust fumes (600÷800 °C) are mixed with open air and the product is colder gas (300÷500 °C). In the case of fixed wing assets, wings entering edges are another source of infrared radiation, aircraft nose and the entering suction hole [2].

There were just aircraft dashboard warning indicators during the seventies and eighties. A crew simply launched decoys or switched on active jammer, after warning alarm. Aircraft with several sensors was even able to locate a direction of an attack. Today, all active and passive parts are integrated to electronically controlled systems (Russian Vitebsk integrates L-136, L-140, L-150, KT-01 and Astra-V). Those systems not only show sort of a danger and the direction of an attack, but also propose optimal solution and in some cases put these propositions into effect according to a threat [2].

2. Homing Missiles Counter-Counter Measures (CCM)

In connection with the above mentioned passive and active aircraft counter measures evolution and development, the missile's CCMs are developed too. Currently developed homing missiles with infrared homing or guidance systems contain logical circuits and systems with an artificial intelligence which count on an artificial jamming (target movement prediction, target radiation multi or hyperspectral analyses, etc.).

2.1. Fundamental Techniques of Missile's CCM

The philosophy and potential of a homing missile CCM against jamming is derived from detection and discrimination of an optical target on its background. Each target which is emerging in the optoelectronic asset field of view is scanned together with its background (other objects, clear or cloudy sky, ground surface, terrain parts, decoys etc.).

The above mentioned detection ability and target discrimination from other objects (e.g. wide area object, decoy; thereafter a background) is therefore subjected to:

- a) differences of target radiation patterns and its background (Fig. 2). It stands for a target **spectral resolution against its background**. Spectral filters on the OE asset or detector input are used with appropriate spectral sensitivity.

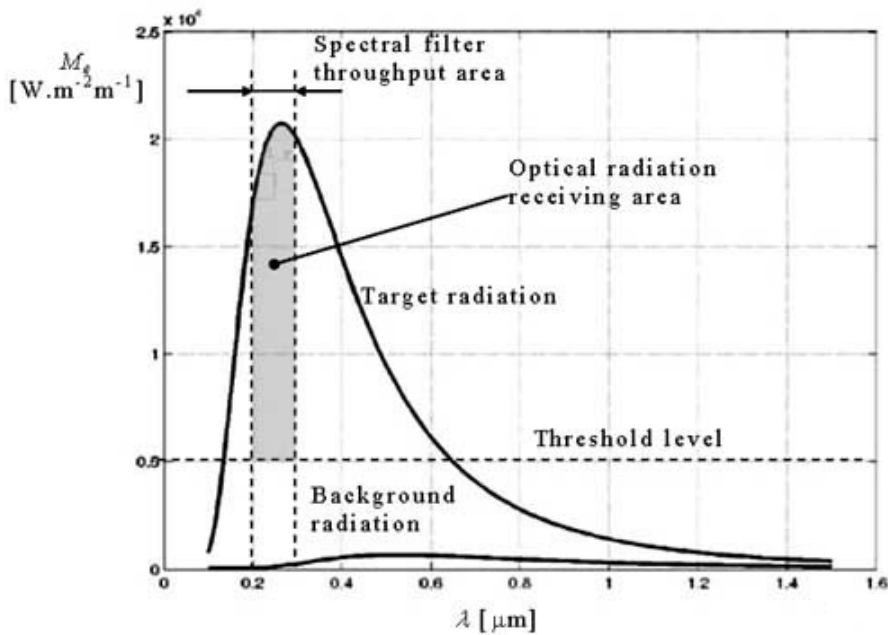


Fig. 2 The target spectral distinction ($T_C = 1100$ K) on its background ($T_P = 550$ K)

If there are no remarkable differences in radiation spectrum for target optical radiation and its background, then target detection ability against its background is subject to

b) nonzero contrast of its radiant characteristics $K_{T/BG} > 0$. That means, it is a target **energetic distinction** against its background, e.g. when for target and background radiant sterance applies $L_{eT} \gg L_{eBG}$ [$W \cdot m^{-2} \cdot sr^{-1}$], see Fig. 3.

If the a) and b) conditions are not satisfied, that means, in case of indistinctive differences in spectrums or small target contrast against background, that there is a possibility to use (for detection and discrimination).

c) proportional or shape differences of target and background. In that case, it is a **spatial target distinction against background** through so-called spatial filters (e.g. optical-mechanical radiation modulator (Fig. 4), matrix detector [3]) or via exploitation of optical system optoelectric asset field of view size control according to angular target size (flexible zoom lens, optoelectric asset field of view electronic reduction (frequency limitation of electric signal output)). When pulse duration (PD) optical-mechanical modulator is used, the intensity of large target depth of modulation is [$m_{HM_BG}(\delta_{BG} = 0.14) = 0.1$] much smaller than the small target depth of modulation intensity [$m_{HM_T}(\delta_T = 0.05) = 0.6$], see Figs 4 and 5.

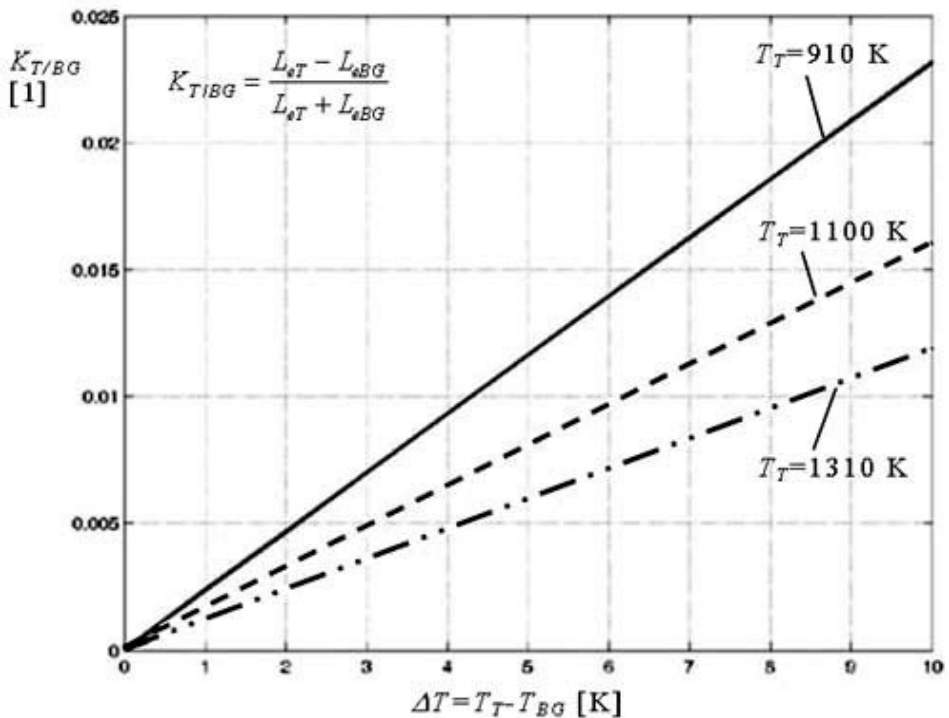


Fig. 3 Thermal target and background contrast characteristic is depending on the target temperature T_c and on the difference between the target temperature and background ΔT , in the spectral band $\Delta\lambda = (3\div 5) \mu m$, with emissivity $\epsilon_{C,P} = 1$

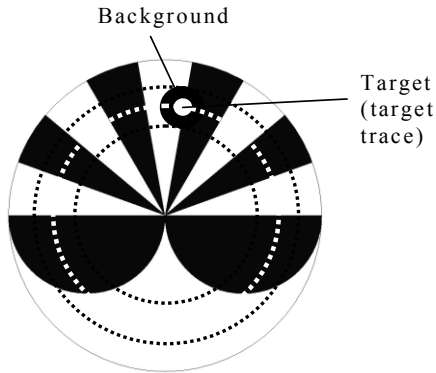


Fig. 4 Explanation of the principle of PD spatial filtration with different target (white) and background (black) size

According to circumstances, there are other factors that effect influence target detection and discrimination, e.g.

- d) Differences between target colours (camouflage) and background colour (this factors are evident in the visible part of optical spectrum only).
- e) Different target and background behaviour during scanning (its movement and movement parameters, e.g. different **angular velocities**).

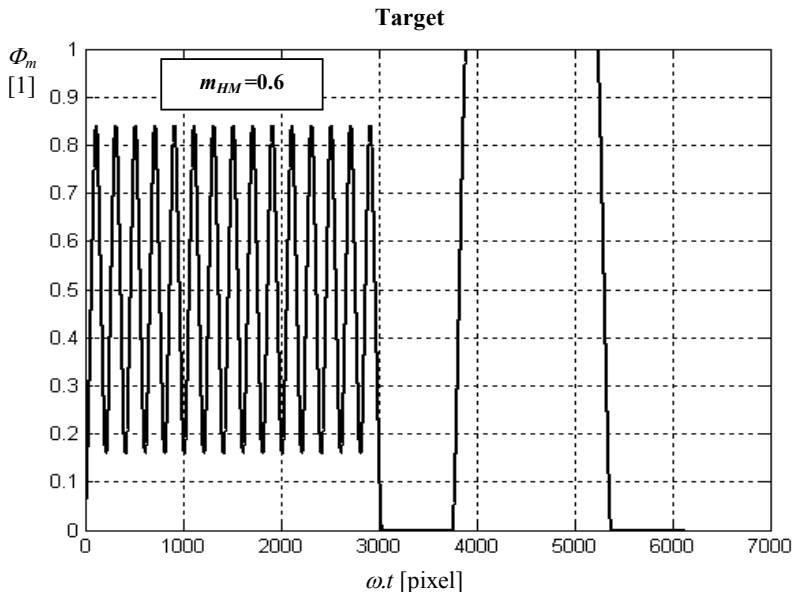


Fig. 5a Modulated radiation progressions in an PD modulator (Fig. 4); target semi-diameter $\delta_T = 0.05$, range from the modulator centre $\rho_T = 0.7$; number of elements $n = 15$; the range of 6000 pixels corresponds to one revolution of modulator about the angle of 2π

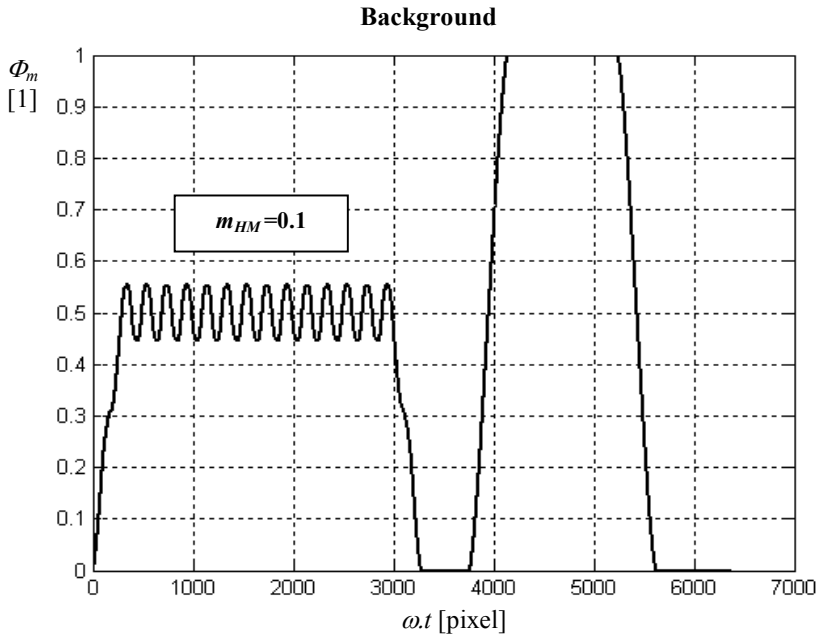


Fig. 5b Modulated radiation progressions in an PD modulator (Fig. 4); background semidiameter $\delta_{BG} = 0.14$, range from the modulator centre $\rho_{BG} = 0.7$; number of elements $n = 15$; the range of 6000 pixels corresponds to one revolution of modulator about the angle of 2π

According to the above mentioned conditions for target detection and discrimination against its background a) to e), general homing missiles protection possibilities against OE jamming are eminent, as well as means and principles of missiles jamming, and resultant defended objects protection assets construction.

2.2. Additional Homing Missiles CCM

a) Resistance let us say protection against passive infrared seekers (which uses radiation modulation in accordance with pulse duration or pulse position) jamming is performed via specific functions [1]:

- frequency signal filtration with reference level comparison;
- detected object discrimination according to pulse width;
- desired (attempted) target tracking according to signal level;
- periodical individual receiver blocking (desired signal keying) – field of view electronic reduction (constant or dependent);
- all receivers temporal aperiodic blocking;
- seeker position control during a temporal receivers blocking according to target movement prediction;
- detected target discrimination according to spectral radiation pattern;
- **detected target discrimination according to the relationship of spectral radiation intensity of two (or more) wave lengths, see Chapter 3;**

- detected target discrimination according to its angular movement velocity regarding a seeker.

The above-mentioned functions could be realized in receivers as well as in protection circuits. Their main task is to hold unwanted signals, but to pass the wanted target signals to the deviation scanning circuits. For detailed function description, see [1].

b) Guidance system protection circuits which use laser semi-active or active seeker serve as a suppression of disturbing optical signals influence to homing missile guidance process. Generally, they insure resistance against natural noise, intentional artificial jamming by foe assets and unintentional artificial jamming by own assets.

Self-jamming assets are especially ground and on-board laser markers. In this case and as a primary jamming source could be as a cooperating marker as a marker which supports another missile guidance. The jamming starts e.g. as a consequence of radiation deflection or dispersion from the objects around a wanted target and if these objects are in the field of view of a seeker. Due to the fact that this field of view is quite large, this situation could easily happen. A usual way how to increase the resistance is via field of view narrowing.

Jamming countermeasure is done through a wanted target electric signal extraction according to its parameters. For this purpose, the following functions are implemented into the guiding system protection circuits [1]:

- signal discrimination according to pulse rise time, pulse falling edge time and pulse width,
- pulses comparison with noise level integrand,
- automatic signal level tracking,
- last pulse selection via long tracking window,
- last pulse selection via short tracking window,
- pulses presence monitoring,
- pulse frequency rate measurement and measured value vs. reference value comparison,
- code target irradiation.

For more detailed function description see [1].

3. Target Optical Radiation Multispectral Analyses

3.1. Lead-in Information

At the beginning of this article (Chapter 1.1 “Aircraft countermeasure basics”), the basic principles of optical decoys were introduced. These decoys have only one purpose which is to make enough infrared (generally optical) radiation in the spectral area of used seeker photo detector (Fig. 1).

When high temperature heat sources (600 to 1400 K) are used, it is quite simple to make such decoy and thereafter to jam seeker photo detectors. There is enough radiation produced to saturate photo detector (e.g. InSb) sensitive in spectral area of $\Delta\lambda = (3\div 5) \mu\text{m}$, when a source of 600 to 1000 K heat is used (Fig. 6). If there is no other countermeasure applied (e.g. radiation modulation), a missile could be re-guided to more intensive decoy. For missiles such as a Strela-2, Stinger, Sidewinder, R-60 etc., a non-cooled photo detectors with spectral sensitivity around $2 \mu\text{m}$ are used. In that case, a heat source at 1100 to 1300 K is enough.

With the knowledge of intensity maximum of a protected object spectral radiation $M_{eC_MAX}(\lambda_{C_MAX}, T_C)$ and with usage of decoy with enough radiation at wave length of $\lambda_{KC_MAX} = \lambda_{C_MAX}$, optimally $M_{eC_MAX}(\lambda_{C_MAX}) = M_{eKC_MAX}(\lambda_{KC_MAX})$, the probability of guided missile seeker jamming is high. To lower this probability, the **multispectral* (or hyperspectral†) analyses of target radiation** could be used, that means a system of several (two, three or more) photo detectors with different spectral (quite wide) sensitivity areas.

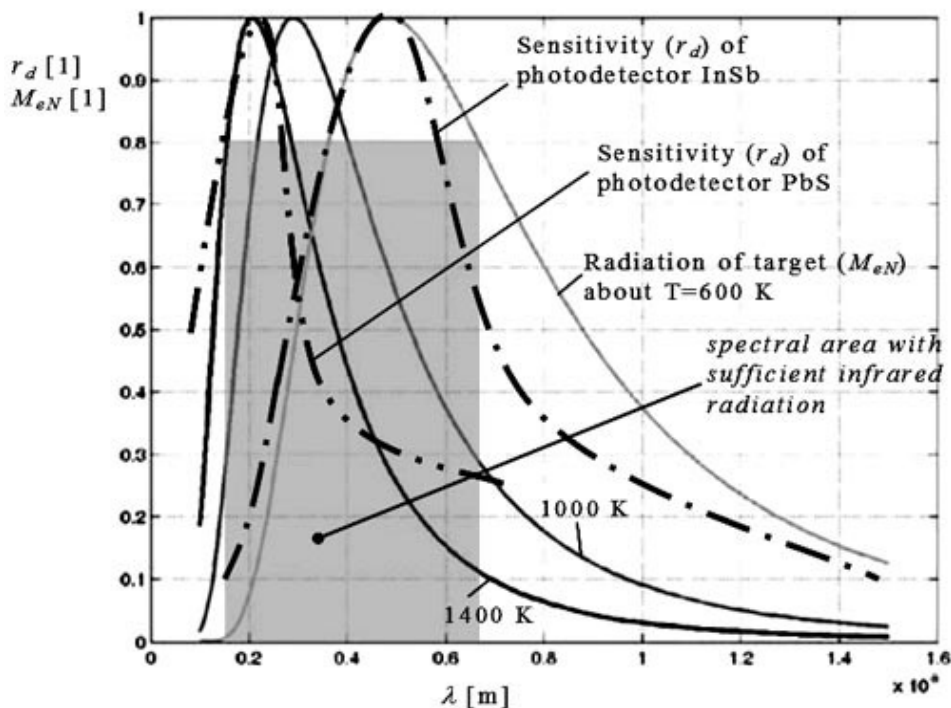


Fig. 6 Spectral area of decoy's infrared radiation (M_{eN}) coverage at temperatures $T = 1400$ K, 1000 K and 600 K and with InSb photo detector spectral sensitivity (r_d) ($T = 77$ K) and PbS ($T = 250$ K)

3.2. Aircraft or Decoys Radiation

The main prerequisite during decoys production (which is not completely fulfilled) is that the aircraft radiation is fully in the constant heat radiation and emissivity sources category (furthermore with known values), and spectral distribution of the aircraft radiation intensity fits to the Planck law (1). The main heat sources are not only exhaust fumes jets, suction holes, entering edges etc., but also exhaust fumes

* Multispectral detection is detection within two, three or more relatively wide spectral bands, with a distance between each other maximum tens of micrometers.

† Hyperspectral detection is detection at many (tens or hundreds) wave lengths with distance between each other maximum tens of nanometers within one or several spectral bands.

containing less or more solid particles (carbon, etc.). Exhaust fumes radiation does not have the heat source character. Maximum intensity of exhaust fumes radiation, independently of their temperature, has wave lengths 2.7 μm and 4.3 μm [4].

For the intensity of heat target at the temperature T_C [K], emissivity $\varepsilon_c(\lambda, T_C)$ and wave length λ is

$$M_c(\lambda, T_C) = \frac{c_1}{\lambda^5} \left[\exp\left(\frac{c_2}{\lambda \cdot T_C}\right) - 1 \right]^{-1} \cdot \varepsilon_c(\lambda, T_C), [\text{W} \cdot \text{m}^{-3}] \quad (1)$$

where the first radiation constant is $c_1 = 3.7417 \cdot 10^{-16} [\text{W} \cdot \text{m}^2]$ and the second radiation constant is $c_2 = 0.0143 [\text{m} \cdot \text{K}]$. Characteristic of ideal heat source radiation intensity lay-out at the temperature 1000 K is in Fig. 7.

To make a decoy with the same radiation characteristics is difficult, because decoy pyrotechnical generators radiation does not have a character of heat source radiation either. An example of possible real decoy radiation characteristic M_{KC} at the temperature 1000 K is depicted in Fig. 7. The existence of unspecific differences in radiation intensity distribution is evident. The match of radiation intensities could exist at one or more wave lengths. Other spectral radiation intensities are mutually different. These shape differences in emissive characteristics could be used to identify specific target through multispectral analyses of radiating entity.

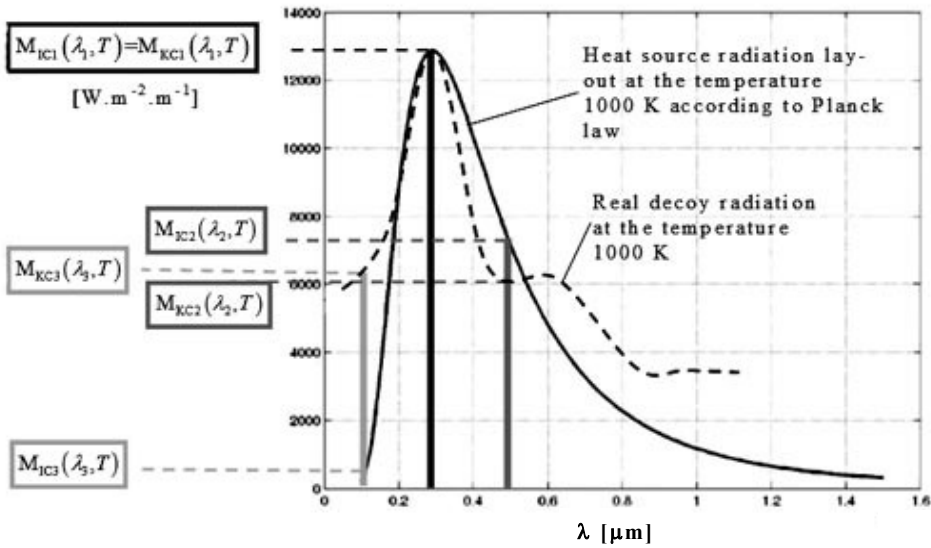


Fig. 7 Characteristic of ideal heat source radiation intensity M_{IC} lay-out and a real decoy model M_{KC} at the temperature of 1000 K

3.3. Multispectral Analysis of Target Radiation Principle

The principle of multispectral (or hyperspectral) analysis of target radiation is based on determination “equality rate” of the shape of actual target emissive characteristics (e.g. M_{KC}) and reference characteristics (e.g. M_{IC}). The ground of method of

multispectral analysis of target radiation is detection of radiation intensity in chosen characteristic spectral bands (Fig. 7) and receiving of radiation intensity ratios according to

$$P_{IC1} = \frac{M_{IC2}}{M_{IC1}} [1], \quad P_{IC2} = \frac{M_{IC3}}{M_{IC1}} [1], \quad (2a, 2b)$$

$$P_{KC1} = \frac{M_{KC2}}{M_{KC1}} [1] \text{ and } P_{KC2} = \frac{M_{KC3}}{M_{KC1}} [1]. \quad (3a, 3b)$$

Consequently, the levels of ratio's matches are analyzed. In the absolute variant of evaluation, if the below stated conditions are met:

a) $P_{KC1} = P_{IC1}$ and $P_{KC2} = P_{IC2}$, a target is taken as a “true/real target”; (4a)

b) $P_{KC1} \neq P_{IC1}$ or $P_{KC2} \neq P_{IC2}$, a target is taken as a “decoy”. (4b)

According to (4a), the full match is a very strict (rather theoretical) criterion that could not be fulfilled even in the case of true/real target, e.g. according to the selective atmosphere attenuation.

One practical and usable way of decision on the “true/real” or decoy target can be found on extension of exact value of rate P_{IC} to the range of values $P_{IC} \pm \Delta P$, in which a target is taken as a “true/real target”. Zone ΔP can be expert determined. Value of P_{IC1} and P_{IC2} ratios are taken as reference, to which the actual measured radiation of unknown target is related. This is expressed through P_{IC1} and P_{IC2} ratios. Then the target is sorted as a “true/real target” if:

$$P_{KC1} \in \langle P_{IC1} - \Delta P, P_{IC1} + \Delta P \rangle \text{ and } P_{KC2} \in \langle P_{IC2} - \Delta P, P_{IC2} + \Delta P \rangle, \quad (5)$$

where ΔP is the level of difference between reference target radiation and measured target. The bigger the ΔP , the bigger can be the difference between reference and real target, which creates a higher probability that the evaluated target is a decoy and vice versa. The simplicity of this evaluation type about right (true, real) or decoy target is an advantage. The accuracy of evaluation dependence on the size of parameter “equality rate” ΔP is a disadvantage. Determination of this right (true, real) value is a relatively hard task.

Another sophisticated decision criterion could be defined in conjunction with fuzzy logic. So the “equality rate” parameter ΔP is determined by so-called “**degree of truth**” and for the evaluation about “true/real” or “decoy” target is defined by so-called “**fuzzy rule**”. For the solution of this task it is possible to use for example Matlab software and its Fuzzy Logic Toolbox extension from MathWorks company, Inc., which contains graphical editors of “degree of truth” and “fuzzy rule” editor.

4. Conclusion

This paper, introduces contemporarily used aircraft CM methods against homing missiles (especially in infrared spectrum), as well as missile CCM against decoys. General philosophy of one method of homing missiles (guided especially in infrared spectrum) protection against artificial jamming is introduced here. That method is multispectral analysis of target radiation (target identification according to radiation intensity lay-out). The possibilities of determination “**equality rate**” about shape of

actual target emissive characteristics and reference characteristics are presented here. This method decreases the probability of guiding the missile to a decoy, but on the other hand the construction of such a seeker is difficult and more expensive. Very difficult and not explicit is also the “right” definition of parameter “**equality rate**” ΔP . Fuzzy logic tool utilization is one of perspective ways of determination this parameter.

As a promising successor of multispectral method appears the hyperspectral analyses [5], which allows more accurate target identification, but is technologically more difficult and more expensive.

References

- [1] NĚMEČEK, J. *Optoelectronic and Electronic Equipments in Systems of Aircraft Armament II.* (Optoelektronická a radiotechnická zařízení v systémech výzbroje letadel II.) Brno : Military Academy in Brno, 2002. 60 p.
- [2] FOJTÍK, J. Self protection of helicopters – old problem, new solutions (Vlastní ochrana vrtulníků – starý problém, nová řešení). *ATM*, 2010, volume 42, no. 5, p. 50-52. ISSN 1802-4823.
- [3] DOSKOČIL, R. *Optoelectronic Seeker of a General VSHORAD Rocket System* (Optoelektronický koordinátor univerzálního raketového kompletu blízkého dosahu) [PhD Thesis]. Brno : University of Defence, 2007. 196 p.
- [4] DOSKOČIL, R. *AD Weapons Systems III.b* (Zbraňové systémy PVO III.b). Brno : University of Defence, 2009. 93 p.
- [5] BACHMANN, AS., HOLZWARTH, A., RICHTER, R., HABERMEYER, M., BORG, E. and MÜLLER, A. Image and Sensor Fusion for Airborne Hyperspectral Sensors. In *DIN-Workshop FUSION*, Berlin : DIN, 2006.

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