Volume XXIII 2020
ISSUE no.2
MBNA Publishing House Constanta 2020

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: Catalin Clinci and Gheorghe Ichimoaei, Scientific Bulletin of Naval Academy, Vol. XXIII 2020, pg.75-78.

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-20-I2-010

A method to compute detection range for electro optical transducers used for anti-ship missiles guidance

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Abstract. In this paper we briefly present a method to compute detection range for electro optical transducers used for naval missiles guidance.

Keywords: infrared, anti-ship missile, homing system, detection range

1. Introduction

The computation of detection range for electro optical transducers used for anti-ship missiles guidance, is a very challenging problem, both in mathematical model and physical model.

The solution complexity is deriving from large number of variables and the random interaction between them. In order to establish a computing algorithm, we identified four categories of variables which are influencing the spectral density of radiant energetic flow, focused on the photosensitive element of a missile:

- Transfer functions and technical characteristics of infrared radiation receivers;
- Energetic ratio between infrared ration of a source and environment;
- Relation between source and transducer (movement or/and position);
- Influence of environmental conditions in the propagation of radiant energetic flow.

The mail goal of this paper is to establish an algorithm to compute the detection range of passive electro optical transducers which are used by anti-ship missiles for guidance.

2. General considerations

In our days when electronic warfare systems and small caliber naval artillery systems are the biggest enemies of anti-ship missiles. In these conditions, the effectiveness of anti-ship missile depends on:

- Reduced time of flight for missile, which supposed an accurate computation and selection of firing range;
- Missiles salvos should be organized in correlation with enemy counteraction and hydro-meteorological conditions;
- Combination between active and passive guidance systems;
- Optimal scheduling of missile trajectory.

The passive electro optical guidance systems are hard to be jammed and the range of such a system is directly affected by the hydro-meteorological conditions. Keeping in mind this assumption, we will try to develop a mathematical model which could be used for determination of the detection range for electro optical guidance systems, taking into consideration: parameters of radiating source, environmental parameters, laws of propagation of radiant energy through the marine atmosphere (absorption law and atomic/molecular dispersion law), and transducer parameters.

3. Analytic method for computing the detection range for passive electro optical systems (EOS) of anti-ship missiles

The detection range of passive electro optical systems, D_{ef}, depends on:

- Technical characteristics of electro optical systems (EOS);
- Main characteristics of infrared radiation of the source and environment;
- Reciprocal position of the source and transducer;
- Propagation of radiant energy through the marine atmosphere from source to receiver.

Starting from these assumptions and taking into consideration that every ship could be considered a *gray body,* according with Planck's law, the spectral density of energy luminance for source, at T_s temperature, could be computed with:

$$L_{c,\lambda} = \varepsilon_{\lambda,Ts} C_1 \int_{\lambda_{min}}^{\lambda_{max}} \lambda^{-5} \left(e^{\frac{C_2}{\lambda * T_s}} - 1 \right)^{-1} d\lambda, \text{ where:} \quad (1)$$

$\varepsilon_{\lambda,Ts}$ – Spectral emissivity of the source (target);

$C_1 = c^2 h = (5{,}994 \pm 0{,}002)10^{-17}\, W/m^2$

$C_2 = ch/k = (1{,}4388 - 0{,}00007)10^{-2}$ Planck's constants

λ – Wavelength for peek energy of the source.

The spectral density of energy luminance for environment could be computed with the same relation, in this case we might use $\varepsilon_{\lambda,Tf}$ as spectral emissivity of the environment, and T_f for environment temperature.

Spectral density of useful energy luminance which is received by EOS, is the difference between energetic flow of the source (target) and energetic flow of the environment. In the same time, the radiating surface of environment, S_f, is directly influenced by the effective radiating surface of the target.

Using Lambert's Law, the spectral density of the energy emitter of the source is given by:

$$M_{e,\lambda_s} = \pi * L_{e,\lambda_s}, \quad (2)$$

And spectral density of energetic luminance for active surface of EOS is given by:

$$E_{e,\lambda} = I_{e,\lambda_s} * \frac{1}{D^2}, \text{ where:} \quad (3)$$

I_{e,λ_s} – spectral density for energetic intensity corresponding for a source which is emitting a radiation with λ_s wavelength, in a solid angle bigger than 1 steradian;

D^2 – Distance between source and receiver.

Taking into consideration relations (1), (2), (3) energetic flow radiated by target, received in the missile transducer is given by:

$$\Phi_{e,in} = \varepsilon_{\lambda,T_s} S_s \frac{d^2}{4D^2} C_1 \int_{\lambda_{min}}^{\lambda_{max}} \tau_s \lambda^{-5} \left(e^{\frac{C_2}{\lambda T_s}} - 1 \right) d\lambda, \quad (4)$$

Where: τ_s - the coefficient of transparency of the atmosphere for distance D.

The same relation could be used to compute energetic flow radiated by environment:

$$\Phi_{e,f,in} = \varepsilon_{\lambda,T_f} S_f \frac{d^2}{4D^2} C_1 \int_{\lambda_{min}}^{\lambda_{max}} \tau_f \lambda^{-5} \left(e^{\frac{C_2}{\lambda T_f}} - 1 \right) d\lambda, \quad (5)$$

Where: τ_f - the coefficient of transparency of the atmosphere for environment radiation.

After the selection and spectral analyses performed by EOS, the flow received is:

$$\Delta\phi_{e,in} = \phi_{e,in} - \phi_{e,f,in} \quad (6)$$

We should take into consideration some attenuations of the received flow, due to filters and mirrors which are fitted in transducer - η_{EOS}.

In this case, the received flow is given by:

$$\Delta\phi_{e,u} = \eta_{EOS} \Delta\phi_{e,in} \quad (7)$$

Taking into consideration relation (7), the EOS detection range could be computed with:

$$D_{ef} = \frac{d}{2}\sqrt{\frac{\eta_{SOE}C_1}{\phi_{e,pr}}\left[\varepsilon_{\lambda T_s}S_s\int_{\lambda_{min}}^{\lambda_{max}}\frac{\tau_s\lambda^{-5}}{\left(e^{\frac{C_2}{\lambda T_s}}-1\right)}d\lambda-\varepsilon_{\lambda T_f}S_f\int_{\lambda_{min}}^{\lambda_{max}}\frac{\tau_f\lambda^{-5}}{\left(e^{\frac{C_2}{\lambda T_f}}-1\right)}d\lambda\right]} \quad (8)$$

Where:

$\phi_{e,pr}-$ Transducer's threshold value of the energetic flow;

d - Diameter of scanning circle.

Relation (8) is valid if target and receiver are on the same axis. Usually, this condition is not satisfied and we should take into consideration two angles:

- Angle α – between target and missile;
- Angle β – between EOS and target.

In the same time, based on Stefan-Boltzmann law, we can write next relation:

$$\sigma_i T^4 = C_1\int_0^{\infty}\lambda^{-5}\left(e^{\frac{C_2}{\lambda T}}-1\right)^{-1}d\lambda, \quad (9)$$

Where σ_i – Stefan-Boltzmann constant, $\sigma_i = 5{,}6697 \pm 0{,}029\frac{W}{m^2K^4}$.

In this case, relation (8) could be rewritten as:

$$D_{ef} = \frac{d}{2}\sqrt{\frac{\sigma_i}{\pi}S_S S_{EOS}cos\alpha cos\beta\left(\frac{\varepsilon_S\tau_{S_{EOS}}\tau_S T_S^4}{\phi_{pr}}-\frac{\varepsilon_f\tau_{f_{EOS}}\tau_f T_f^4}{\phi_{pr}}\right)}, \quad (10)$$

Based on these relations and using Mathcad software, we compute some detection ranges for an EOS with $8 \div 12\mu m$ threshold value. The results are showed in the next table:

Table 1

Visibility feature	**Visibility range**	**Atmospheric conditions**	**Degree of visibility**	τ_{atm}	**Detection range (computed)**
Very low	0 – 0,25 ncab	Very strong fog	0	-	-
	0,25-1 ncab	Strong fog or snow	1	-	-
	1-3 ncab	Moderate fog or light snow	2	0,0004	551,4 m
Low	3 – 5 ncab	Light fog	3	0,02	1341,5 m
	5ncab – 1nm	Heavy rain	4	0,14	3899 m
Medium	1 – 2 nm	Rain	5	0,38	10320 m
	2 – 5nm	Light rain	6	0,67	17000 m
Good	5 – 10 nm	Light rain	7	0,82	22570 m
Very good	10 – 27 nm	Clear	8	0,92	24970 m
Excellent	More than 27 nm	Cristal clear	9	0,99	26440 m

4. Conclusions

The EOS used for calculus is efficient when the visibility degree is greater than 4. For visibility degree lower than 4, the missiles equipped passive homing systems (EOS) will not detect the target.

For this reason, any missile should not be launched.

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