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Effect of errors on miss distance of missile trackers in active decoy environment

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ABSTRACT

Lock on missiles are a major threat to vital installations. Soft kill solutions against lock on incoming missiles such as deployment of active decoys can be very effective to war of threat. The weaknesses in onboard missile tracking radars can be gainfully used to increase the miss distance between target and the missile. The effect of geometrical positioning errors of two horn monopulse missile mounted radars has been analyzed in this paper. As so gain differences between the two horns can cause variations in the miss distance. This aspect has also been studied. The variation of miss distance with jammer power to signal ratio (J/S) is also presented. It can be seen that the miss distance is always midway between the target and the decoy. Random angular positioning errors of the missile radar have been analyzed and it is found that the miss distance increases with increase of angular errors.

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1. INTRODUCTION

Friendly targets such as ships, land installations and others have to be protected against incoming lock on missiles. There are both hard kill and soft kill options available for protecting friendly ships and on-land installations. Soft kill options such as deployment of decoys have been used effectively to ward off incoming missile threats. The weaknesses in tracking radar of the missiles have been exploited quite effectively. Miss distances of missiles with active decoy deployed have been computed for various cases and reported in literature [1]. The beam pointing errors in the missile tracking radar on account of geometrical positioning errors modify the miss distance achievable for a given active decoy deployment. This aspect has been studied in detail through Mat lab simulations and reported in this paper.

An active decoy has been one of the most efficient device due to its high deception performance and low cost [2]. For the optimal design of the active decoy, modeling and simulation methods may be required to evaluate the radar jamming performance of the active decoy [3]. In [4-5], the basic requirements for distributed general purpose decoy series (DGPD) have been presented. Hyper spectral signature and corresponding transform domain analysis method has proved effective for discriminating target radiation from decoy used in practice [6]. A new anti-ARM technique using random phase and amplitude active decoys has been presented [7]. The various counter measure techniques against ARM have also been studied [8-15]. In another paper, the deceptive effect of blinking decoys on ARM s have been discussed [16]. The performance evaluation of radar and decoy system counteracting ARM has been reported [17].

In this paper section 2 describes deployment geometry, section 3 mathematical formulations, section 4 geometrical positioning errors, section 5 results and analysis, and section 6 conclusions. The reference paper for this analysis is the paper published by the author earlier [1].

2. MISSILE AND DECOY GEOMETRY

The missile and decoy geometry is shown in Figure 1. Missile is assumed to be located at the origin ‘o’. Target is assumed to be in the terminal phase tracking the target. Hence, angle θ_t is the subtended angle between the projection of the decoy in the X-Y plane and the target which is also located in the X-Y plane.

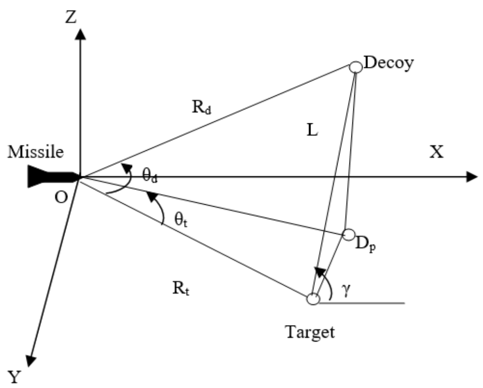

Figure 1. Missile and decoy geometry

The following are the various parameters defining the geometry.θ_d - Angle between decoy and target subtended at the missile; R_d- Distance between missile and the decoy in meters;
R_t- Distance between missile and target in meters;
L- Distance between the decoy and target;
γ- Angle between missile to target line and the target to decoy line.The missile has a monopulse receiver, which has an RF frontend followed by mixer, IF amplifier.

3. MATHEMATICAL FORMULATION

The monopulse radar is assumed to have a two horn monopulse receiving system. The antennas are squinted at θ_0 with respect to missile to target axis, which is the bore sight. The radiation power pattern is assumed to be Gaussian in nature. The angle estimation is done with the standard sum and difference approach. The sum and difference signals are taken at the IF output. Coherent monopulse processing is assumed.Three types of errors can occur in the two horn system.
Case1: Squint angle is changed by $\Delta \theta_0$.
Case2: The gains of the antennas differ by $\Delta G=|G1-G2|$, where G1 and G2 are the gains of the antennas.
Case3: A simultaneous occurrence of case1 and case2.

In the above three cases, signal to noise ratio as observed at IF output is varied. In all the above cases miss distance between the missile and target are computed using sum and difference IF outputs.

$$V_{10t} = \sqrt{(S * G_0 * \exp(-2.776 * ((\theta_t - \theta_0 - \Delta\theta)/\theta_b)^2} + A_n \quad (1)$$

$$V_{1t} = V_{10t} * \sin(\omega t + \Delta\varphi) \quad (2)$$

$$V_{20t} = \sqrt{(S * (G_0 + \Delta G_0) * \exp(-2.776 * ((\theta_t + \theta_0 + \Delta\theta)/\theta_b)^2} + A_n \quad (3)$$

$$V_{2t} = V_{20t} * \sin(\omega t + \Delta\varphi) \quad (4)$$

$$V_{10d} = \sqrt{(J * G_0 * \exp(-2.776 * ((\theta_d - \theta_0 - \Delta\theta/\theta_b)^2} + A_n \quad (5)$$

$$V_{20d} = \sqrt{(J * (G_0 + \Delta G_0) * \exp(-2.776 * ((\theta_d + \theta_0 + \Delta\theta/\theta_b)^2} + A_n \quad (6)$$

$$V_{1d} = V_{10d} * \sin(\omega t + \Delta\varphi) \quad (7)$$

$$V_{2d} = V_{20d} * \sin(\omega t + \Delta\varphi) \quad (8)$$

$$V_1 = V_{1t} + V_{1d} \quad (9)$$

$$V_2 = V_{2t} + V_{2d} \quad (10)$$

Where, V_1- Time domain signal voltage at IF output
V_2- Time domain signal voltage at IF output
V_{10t}-Amplitude of the target echo signal at horn1
V_{20t}-Amplitude of the target echo signal at horn2
V_{10d}-Amplitude of the decoy signal at the output of horn1
V_{20d}-Amplitude of the decoy signal at the output of horn2
S-signal power
J-Decoy repeater power
$\Delta\phi$-Random phase of additive noise
G_0- Gain of receiving antennas1 and 2.
θ_t- Angle between missile and target=0
θ_0- Squint angle of the horns with respect to missile-target axis
θ_B- Half power beam width
ω- Radian frequency at IF.
A_n-Additive noise amplitude
$\Delta\theta$- angular error due to antenna positioning; this is varied between 0 to 0.5 times of θ_0.

$$V_{sum}(f, \theta, t)=V_1 + V_2 \quad (11)$$

$$V_{diff}(f, \theta, t)=V_1 - V_2 \quad (12)$$

The error voltage related to angular tracking error of radar is given by

$$V_{error}(f, \theta, t) = real\ (V_{diff}/ V_{sum}) \quad (13)$$

Where, θ- Angle off bore sight axis of the monopulse antenna system

Simulations have been carried out for studying variation of voltage error V_{error} for various values of active decoy jammer power to radar echo signal ratio J/S (as measured at receiver SUM channel IF output) against γ and L. Miss distance is computed using the relation,

$$R_d^2=R_t^2+ L^2-2.R_t.L.\cos(180-\gamma) \quad (14)$$

4. GEOMETRICAL POSITIONING ERRORS

Computer simulations have been carried out for studying miss distance by considering the errors caused by the above three cases. Since during manufacture and assembly squint angle errors are bound to occur and these errors modify the miss distance significantly. Hence, the squint angle θ_0 is taken as $\theta_0 \pm \Delta\theta$, where Δθ is the random squint angle error. Δθ is assumed to vary up to 50% of θ0. The variation of θ0 with errors is assumed to follow Gaussian distribution. In computer simulations, this aspect is taken into account. Since $\theta_0+\Delta\theta$ is made a random variable, miss distance is computed for every value of θ0+Δθ, mean of miss distance is obtained and plotted. This has been done for all the four cases cited above. Further, in each case, gamma and SNR have also been varied and average and standard deviation of miss distance is obtained. Various parameters affecting deployment have been studied and, mean also calculated. For various values of γ ranging from 100 to 1700, miss distance varies in accordance with the gain. That is, as gain decreases miss distance also decreases. The ranges of the parameters which are used in computer simulations are given below. Miss distance D versus J/S is also computed (Miss Distance is the distance between target and the missile nearest to the target in the presence of decoy).

J/S	-	0 to 30
γ	-	$10^0$to 170^0
L	-	100 to 600meter.
R_t	-	10Km.
G_0	-	0.7 to 1.
Δθ	-	0 to30% of θ_B.

The above has been repeated with a typical IF SNR of 5dB, 10dB and without noise. From the voltage error, the angular error produced by the monopulse system which is calibrated for tracking with a single target has been computed and miss distance in meter is plotted. These are shown in Figure 2. The effects of antenna errors when the latter are nil and at different values on miss distances have been calculated and notified. The mean values of miss distance have been calculated in the conditions the gamma angle from 60^0 to 120^0 and L from 100 to 600 meter separately for the deployment of decoy and these values for the gamma 60^0 and 70^0 are notified in the tables shown in Tables1-2.

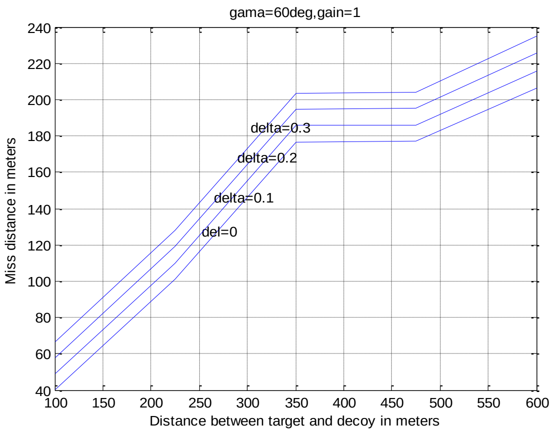

Figure 2. Miss distance variation with L, (without additive noise) at $\gamma=60^0$, R_t=10Km; Antenna error($\Delta\theta$) is 0,0.1,0.2,0.3

Table 1. Mean of miss distance at $\gamma=60^0$

Mean of $\Delta\theta$	Mean of Miss distance at $\gamma=60^0$				
	L=100m	*L=225m*	*L=350m*	*L=475m*	*L=600m*
0.05	37.819	96.303	186.437	158.641	183.824
0.15	44.1633	102.662	192.388	165.303	190.66
0.25	47.108	105.630	195.159	168.4	193.84
0.35	50.192	108.744	198.048	171.632	197.161
0.45	56.44	115.014	203.906	178.183	203.90

Table 2. Mean of miss distance at $\gamma=70^0$

Mean of $\Delta\theta$	Mean of Miss distance at $\gamma=70^0$				
	L=100m	*L=225m*	*L=350m*	*L=475m*	*L=600m*
0.05	42.909	85.3548	252.891	199.965	232.379
0.15	50.687	93.2227	259.393	208.208	241.057
0.25	55.480	98.0690	263.478	213.285	246.390
0.35	58.440	101.059	266.046	216.413	249.668
0.45	63.863	106.537	271.111	222.132	255.682

5. SIMULATIONS AND RESULTS

The gamma values are fixed varying from 600 to 1200 and fixing the antenna angular errors from 0 to 0.5 for the calculations of miss distances. Fixing the antenna error as 0, γ=600, the variations of miss distance with J/S have been simulated for the values of L varying from 100 to 600meter. The above simulation has been carried out for different values of γ from 700 to 1200 are shown in the Figures 3-5. If J/S ratios are less than 5, it is identified that the curves are not steady. When the decoy is deployed to a distance of L=600meter, from the deck of the ship, and at an angle of γ=1100, with no antenna error, and at the noise of 5dB, the calculated miss distance is found to be between 300m and 400m. The decoy deployment is repeated at the same angle and same distance as above with no noise and with no antenna error, the miss distance has found to be 200m to 250m. The mean of miss distance against angular error due to antenna positioning for different γ values is calculated at every L separately. The above simulation has been carried out for J/S=1, J/S=5 and the graphs are shown in Figures 6-11.

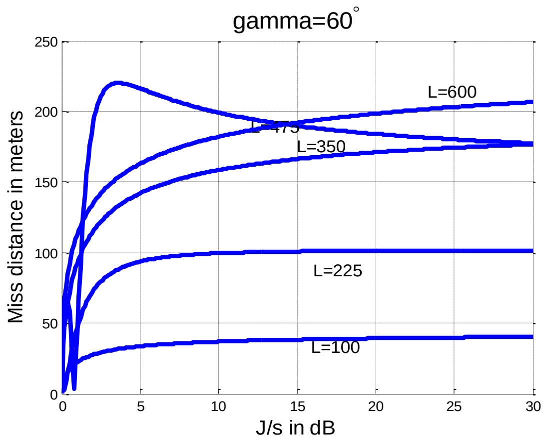

Figure 3. Miss Distance variation with J/S, antenna positioning angular error is 0, (without additive noise) at $\gamma=60^0$, R_t=10Km; L is100 to 600meter

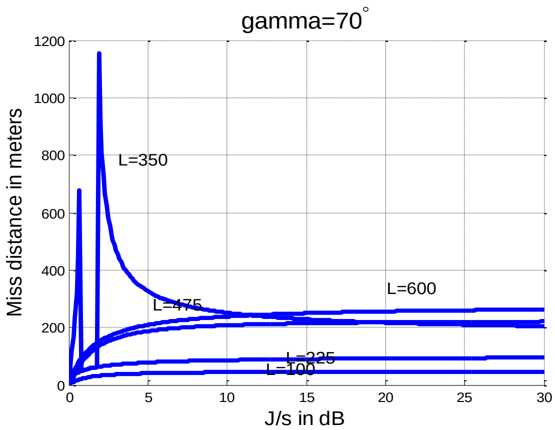

Figure 4. Miss Distance variation with J/S, antenna positioning angular error is 0, (without additive noise) at $\gamma=70^0$, R_t=10Km; L is 100 to 600meter

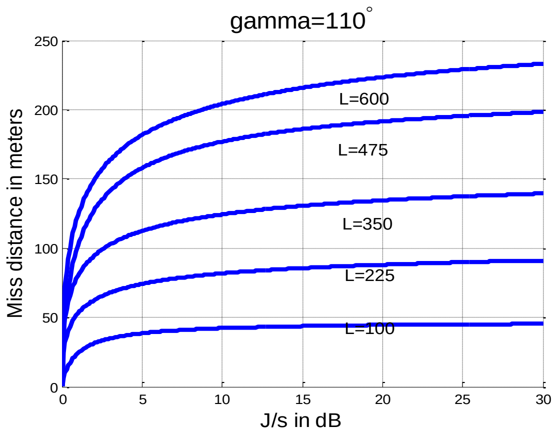

Figure 5. Miss Distance variation with J/S, antenna positioning angular error is 0, (without additive noise) at $\gamma=60^0$, R_t=10Km; L is100 to 600meter

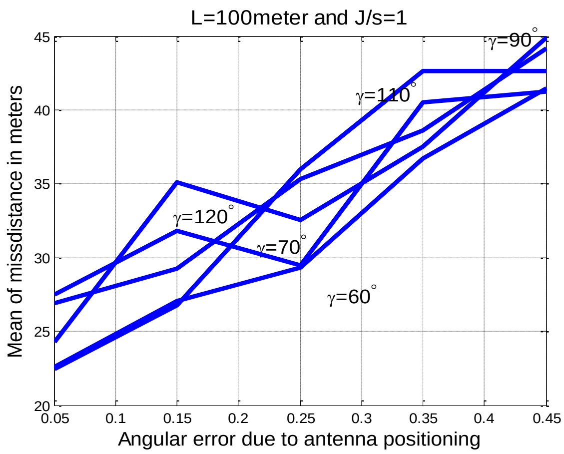

Figure 6. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=100meter,J/S=1,$\gamma=60^0$ to120^0; R_t=10Km

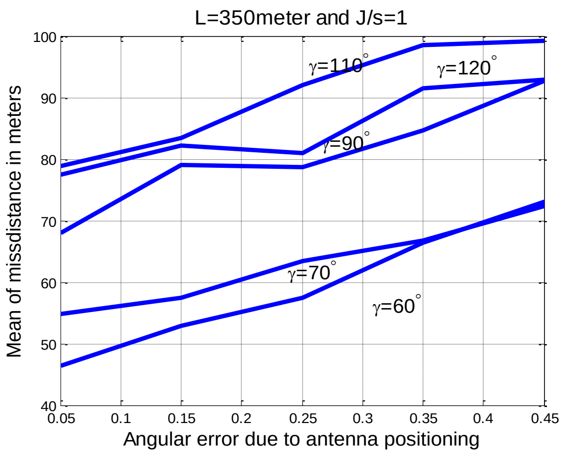

Figure 7. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=350meter,J/S=1,$\gamma=60^0$ to120^0; R_t=10Km

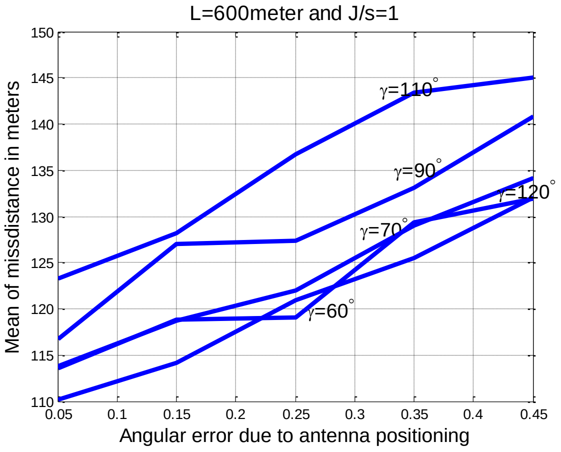

Figure 8. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=600meter,J/S=1, $\gamma=60^0$ to120^0; R_t=10Km

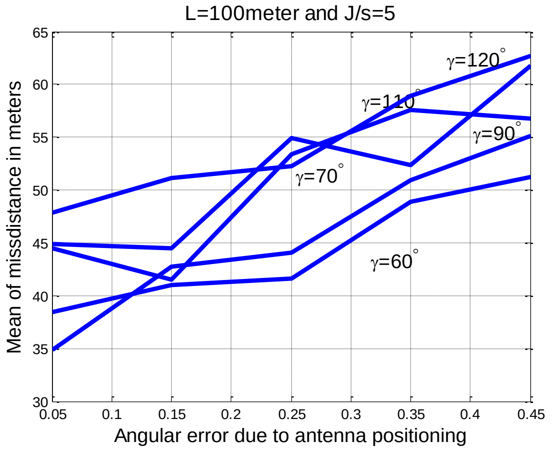

Figure 9. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=100meter,J/S=5, $\gamma=60^0$ to120^0; R_t=10Km

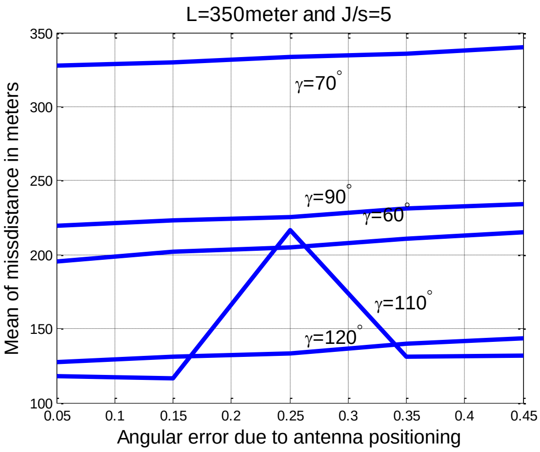

Figure 10. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=350meter,J/S=5, $\gamma=60^0$ to120^0; R_t=10Km

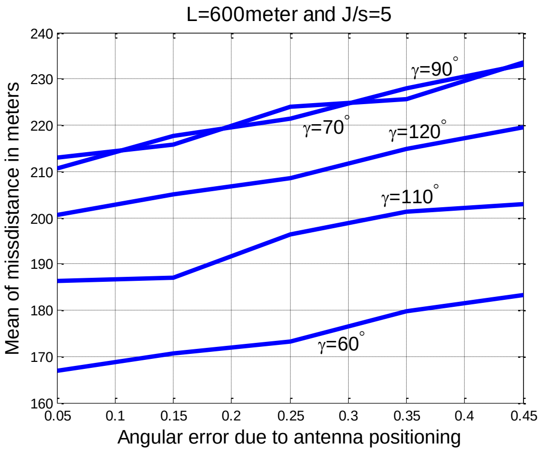

Figure 11. Mean of miss Distance variation with antenna positioning angular error (without additive noise) at L=600meter,J/S=5, $\gamma=60^0$ to120^0; R_t=10Km

6. CONCLUSION

Decoys have been used extensively as soft kill options against the threat of incoming missiles. Two horn monopulse missile radar system has been analyzed for computing miss distance between target and the decoy. Variation of miss distance with J/S ratio and receiver noise has been analyzed and results reported. It has been found that a J/S ratio of 5dB is required for stable operation of active decoys, without considering geometrical antenna errors. Angular error has been taken as a random variable and effect of this parameter on miss distance is analyzed. It can be seen that miss distance increases with antenna positioning angular errors. Therefore, it is essential that the antenna angular errors should be kept to a minimum for reducing the miss distance from the missile standpoint of view and it is beneficial for the friendly target if the missile antenna positioning errors are more.

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