

## IPPN for Anti-Radiation Missile

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### Abstract

This paper investigates the benefits of the Integral Proportional Navigation Guidance (IPNG) scheme and its control loop construction altered from conventional Proportional Navigation Guidance (PNG). It's passive ranging system, and there's a bearing-only information coming in that'll make it unavailable to utilize PNG. For passive ranging missile against slow-moving surface targets, the Integral Pure Proportional Navigation Guidance (IPPN), a variety of IPNG, produces predictable trajectory profiles in which the flight path angle and line-of-sight (LOS) angle are employed only. The guidance parameters that can be optimized to yield the desired hit angle outcome are most likely; the lead angle and flight path angle at handover; the navigation gain; and the bias command at initiation. The controllability for implementation in realistic missile loop is demonstrated through single lag block diagram. The simulation results are also provided.

Key words: Passive ranging, Guidance law, PNG, IPNG, IPPN

### I. Introduction

supersonic anti-radiation missiles(ARM) with 25 fts accuracy and a 300 lbs warhead, which home on RF radar source with a passive fixed staring antenna. The seeker acquisition range is 7 to 11 NM, and the RF spectrum is 0.7 to 1.8 GHz cover all anti-aircraft radar. The mid-course relays on predicted velocity and altimeter. The conical head consists of 4 spiral strip antenna, which provides target offset angles data. The airframe has mid-body wings for control and a fixed-fin tail successful against all types of known anti-aircraft radars in test and Gulf war. The issues addressed are: the mechanisms of the guidance scheme; the hit angle predictability, and its sensitivities to guidance parameters and initiation.

Normally traditional PN would be pretty easy to apply to, and implanting them all within an active sense missile would be a piece of cake. Regrettably, though, it's passive ranging system, and there's a bearing-only information coming in that'll make it unavailable to utilize once it makes angle measurement. Since getting the technical route in front of requirement, we've got an important amendment to PN to suggest based on the passive ranging criterion.

### II. Problem statement

When it comes to air-to-surface missile (ASM) guidance, originally connecting with terminally-guided sub-munitions (TGSM), there is the problem of achieving accurate

guidance in very limited space. Following Trottier [1], this mission looks at the design problem of attacking a tank from a TSGM initially in level flight. Fig. 1 depicts the geometry of the search phase while the TSGM is at altitude  $h$  and flies level at velocity  $V_M$ . The seeker searches the ground at a look-down angle  $\beta$ . The last several decades have witnessed increasingly guidance schemes and seeker technologies for guided weapons. PNG is selected as the steering law for TSGM. For the sake of simplicity, a linear model is considered for the homing head (perfect information) and all TSGM characteristics.

With direction finder (DF) guidance, anti-radiation missiles (ARM) for use against communication and radar emitters carry one or more internal or external antennas which provide directional information on target location over a large signal band-width. ARM requires the capability to home the source of enemy signals. System requirement recommended that ARM get a customized guidance law that would be better suited to its DF seeker. The rotation of the LOS is measured by the DF seeker, which causes commands to be generated to turn the missile in the proper direction. It's not just what ARM with DF guided while hitting ground target that's changing—it's also how to use directional data and offer the best-known flight course. Traditional PNG is not satisfactory in ARM, passive DF only provide angle information, in tracing emitter. However, this does not stop IPPN from setting out on a journey that has led to its becoming the ARM's best guidance law. Instead of LOS rate, IPPN

employs angle data straightly.

When it comes to ARM guidance again, some paths get more consideration than others. The trajectory height of ARM drains interceptor's energy or direct hit, and the hit angle often stifles their kill to destroy in anti-radiation action. In situation such as this, guidance law turns to one thing: finding a trajectory height to flee to! The advanced requirement of ARM is guidance with lofting trajectory, high dive angle at hit and high accuracy, which is presented in Fig. 2. Fig. 2 also depicts the guidance issues of ARM.

In traditional PNGs, are known for its robust and implement, but they have limitations in trajectory shaping, though, and become necessary to have evolution. IPPN with lofting and hit angle adjustment are valuable and its sensitivity are worthy of attention as well. Lofting is an inevitability of ARM trajectory. Some strategies are in desperate need of it, while most of ASMs want little. Early ASMs attack and apply guidance law without the need for shaping its trajectory. Otherwise, as scenario settled in mid-course phase, ARMs acquire more transition and adjusting for what they need. For instance, switching time for diving in is extremely useful as limited tolerance, and transition to homing mode for fine tracking can be collected from self-initiated range information. The issues of ARM guidance are: the mechanism of the IPPN scheme the trajectory profiles sensitivity to guidance parameters and initiation the hit angle predictability and its sensitivity to parameters.

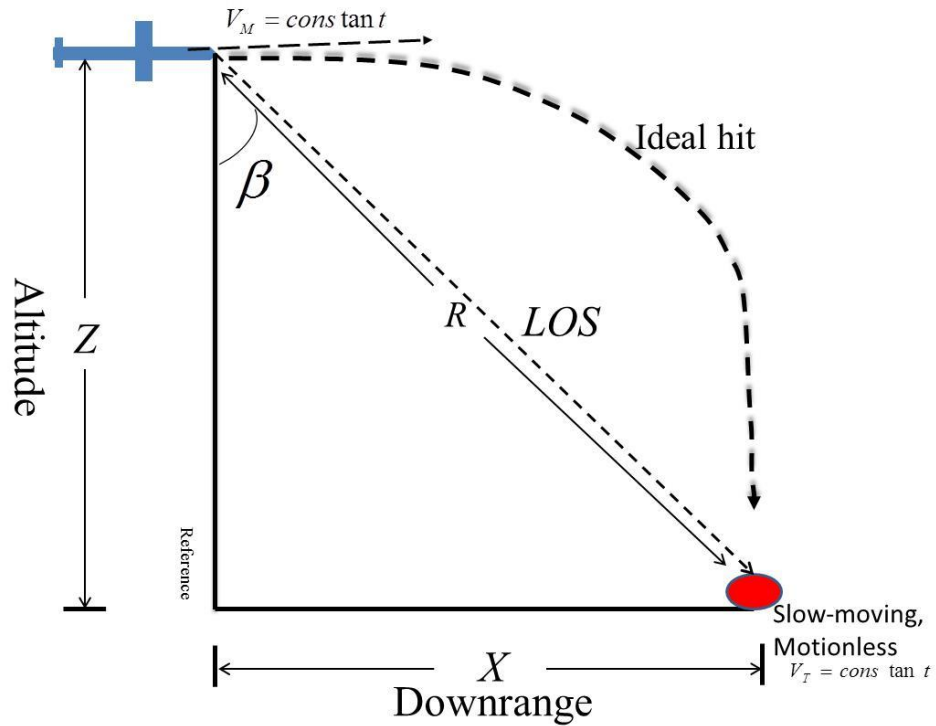


Fig.1. Sketch terminal homing of TGSM and ASM.

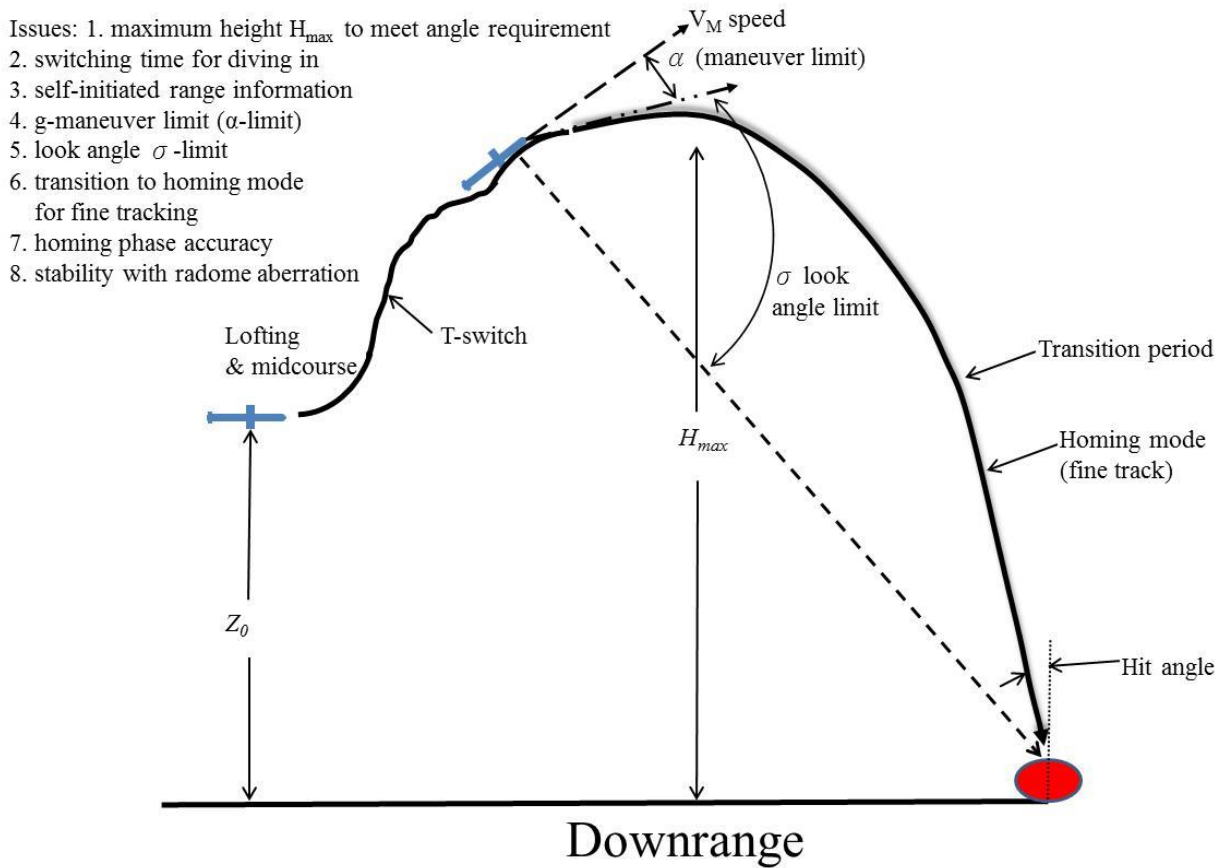


Fig.2. Guidance issues of ARM.

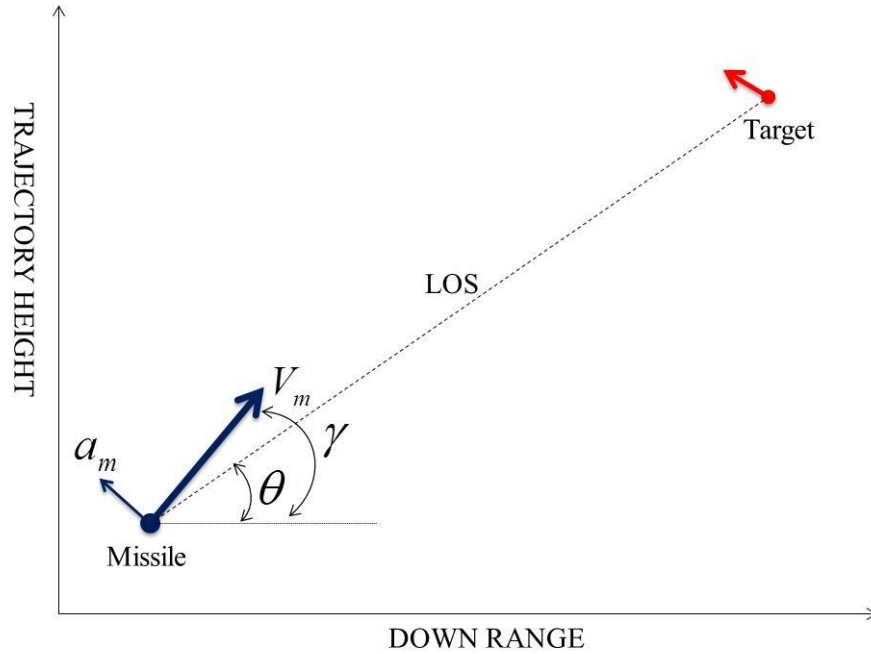


Fig.3. Intercept geometry.

### III. Guidance law design

As usual, the missile-target intercept model can be depicted in Fig. 3, where the following variables are defined:  $\theta$  is the LOS angle;  $\gamma$  is the missile path angle;  $V_m$  is the missile velocity;  $a_m$  is the missile acceleration.

Although the advantage of PNG, such as effectiveness, robustness, and ease of implementation, together with its history of success to the deployment of missile systems employing PNG, combine to cause PNG to remain attractive[2-10]. The difficulties in employing PNG at interception stem from uncertainty in LOS rate ( $\dot{\theta}$ ). The design of a guidance law for ARM is primarily affected from the knowledge of the LOS angle capability. One way to create a new approach is to use mathematical expressions that engineers will

quickly grasp.

Based on PNG law [3,9,11-13]:

$$\dot{\gamma} = N\dot{\theta} \quad (1)$$

$N$  is a Proportional Navigation Constant.

Integrating (1), it have

$$\gamma - \gamma_0 = N(\theta - \theta_0) + C \quad (2)$$

$\gamma_0$  is the initial path angle;  $\theta_0$  is the initial LOS angle;  $C$  is a constant, representing the accumulation of head error, leading angle and noise. (2) can be rewritten as:

$$\gamma = N(\theta - \theta_0) + \gamma_0 + C \quad (3)$$

Let  $M = \frac{\gamma}{\gamma - C}$ , (3) can be arranged as:

$$\gamma = M[N(\theta - \theta_0) + \gamma_0] \quad (4)$$

Equation (4) is the mathematical expression for IPNG.  $M$  is another Proportional Navigation Constant.

According to the direction of the commanded acceleration various forms of PNG exist. In the literature two basic forms of PNG have been considered in detail: pure proportional navigation (PPN) [2,14-17] and true proportional navigation (TPN) [18-21]. In PPN, the commanded missile accelerations are applied normal to the missile velocity. In TPN, the commanded missile accelerations are applied normal to the line-of-sight (LOS). Considering a motionless target and an ARM, the IPPN equations are more suitable for engagement scenario, ITPN scheme not available [22].

Following PPN equation of motion, yields

$$\dot{\gamma} = \frac{a_m}{V_m} \quad (5)$$

Substitute (5) into (1), the PPN guidance law is obtained:

$$a_m = KV_m \dot{\theta}, \quad K \text{ is a gain.} \quad (6)$$

In (6), the meaning of guidance loop is

$$a_m = KV_m * Error_{PPN} \quad (7)$$

$$\text{where } Error_{PPN} = \dot{\theta} \quad (8)$$

From (2), the operation of integrating PNG law, we have

$$\frac{(\theta - \theta_0)}{\Delta t} = \frac{\gamma - \gamma_0}{N\Delta t} + \frac{C}{N\Delta t} \quad (9)$$

Choose guidance loop command error  $\delta$ , so that the LOS rate  $\dot{\theta}$  always equal zero.

$$\delta = -C = N(\theta - \theta_0) - (\gamma - \gamma_0) \quad (10)$$

$$\text{And } Error_{IPPN} = K_s(\theta - \theta_0) - (\gamma - \gamma_0) \quad (11)$$

Using (11), the net effect on acceleration command generation for IPPN becomes

$$a_m = K_i V_m * Error_{IPPN} \quad (12)$$

Let the autopilots are perfect with zero-lag, the normal acceleration of the IPPN command missile is given by

$$a_m = K_i V_m [K_s(\theta - \theta_0) - (\gamma - \gamma_0)] \quad (13)$$

where  $K_i$  is the loop gain of the IPPN command guidance loop, and  $K_s$  is the proportional navigation gain.

Equation (13) is the IPPN guidance law. The basic differences between IPPN command and PPN command lay in the method for issuing acceleration command to the missile flight control system. For the IPPN command, the acceleration command to missile autopilot is proportional to the flight path angle loop error. The IPPN command flight control system is realized with LOS angular position command and flight path angle feedback. Comparing (4) and (13), IPPN is similar to IPNG in quantity. IPPN is descended from IPNG.

#### IV. IPPN implement model

The PPN guidance & control loop are shown in Figure 4[3-10]. The IPPN guidance & control loop are presented in Figure 5[23,24]. There are three loop closures in the IPPN guidance portion. In the outer main LOS loop, the inertial LOS  $\theta_{los_0}$  are utilized to issue a proportional command

to the inner gamma loop.  $K_s$  is the conventional navigation gain. The LOS position information are scenario kinematic feedback,  $\theta_m$ . The inner gamma loop indicates that the autopilot acceleration command  $a_c$  are proportional to the error of the gamma loop. This indirect setup, can be shown, inserts an effective differentiator between  $a_c$  and  $\theta_{los_0}$ , thus renders the IPPN to have all the companionate feature of a conventional PPN guidance scheme, the missile are assumed to have an alfa-autopilot. The PPN guidance & control loop are shown in Fig. 4[3-10]. The IPPN guidance & control loop are presented in Fig. 5[23,24]. There are three loop closures in the IPPN guidance portion. In the outer main LOS loop, the inertial LOS  $\theta_{los_0}$  are utilized to issue a proportional command to the inner gamma loop.  $K_s$  is the conventional navigation gain. The LOS position information are scenario kinematic feedback,  $\theta_m$ . The inner gamma loop indicates that the autopilot acceleration command  $a_c$  are proportional to the error of the gamma loop. This indirect setup, can be shown, inserts an effective differentiator between  $a_c$  and  $\theta_{los_0}$ , thus renders the IPPN to have all the companionate feature of a conventional PPN

guidance scheme, the missile are assumed to have an alfa-autopilot.

Set initial condition  $\gamma_0 > \theta_0$  and the flight path angle feedback  $\gamma_f$  from a first-order autopilot.

$$\begin{aligned}\gamma_f &= a_c * \frac{1}{T_{ap}s+1} * \frac{1}{V_M} * \frac{1}{s} \\ &= Error * K_i * V_M * \frac{1}{T_{ap}s+1} * \frac{1}{V_M} * \frac{1}{s} \\ &= [N(\theta - \theta_0) + \gamma_0 - \gamma_f] * K_i * V_M * \frac{1}{T_{ap}s+1} * \frac{1}{V_M} * \frac{1}{s} \\ &= \frac{[N(\theta - \theta_0) + \gamma_0]K_i - \gamma_f K_i}{(T_{ap}s+1)s}\end{aligned}\quad (14)$$

Rearranging,

$$\left[1 + \frac{K_i}{(T_{ap}s+1)s}\right]\gamma_f = \frac{N[(\theta - \theta_0) + \gamma_0]K_i}{(T_{ap}s+1)s}\quad (15)$$

$$\gamma_f = \frac{N(\theta - \theta_0) + \gamma_0}{\frac{s(T_{ap}s+1)}{K_i} + 1}\quad (16)$$

Substituting (16) into (14), for large  $K_i$  and small  $T_{ap}$ ,

$$\begin{aligned}a_{IPPN} &= a_c = \gamma_f * s * V_M * (T_{ap}s+1) \\ &= \frac{N(\theta - \theta_0) + \gamma_0}{\frac{s(T_{ap}s+1)}{K_i} + 1} * s * V_M * (T_{ap}s+1) \\ &= [N(\theta - \theta_0) + \gamma_0] * \frac{1}{\frac{s}{K_i} + 1} * V_M * s\end{aligned}\quad (17)$$

The IPPN closed-loop can be approximately expressed as

$$a_{IPPN} \approx K_s * V_M * LOS * s * \frac{1}{\frac{s}{K_i} + 1}\quad (18)$$

Equation (18) indicates IPPN are equivalent to PPN subjecting to a first order

lag with a time constant normally. The benefits of the IPPN command are the availability of an additional gain and a summing joint, which can be optimized to yield predictable results at vertical hit for terminal shaping homing with the proper initial conditions. The flight control system for the IPPN command can be simplified into three equivalent joint for error command generation as Fig. 6.

In Figure 6,

$$\begin{aligned} & N(\theta - \theta_0) - (\gamma_f - \gamma_0) \\ &= N(\theta - \theta_0) - (\theta + \eta) + (\theta_0 + \eta_0) \quad (19) \\ &= (N-1)(\theta - \theta_0) - (\eta - \eta_0) \end{aligned}$$

As a comparison, PPN command will be

$$a_c = K * V_M * LOS * s \quad (20)$$

The IPPN and PPN have been shown to be analytically similar, that acceleration commands issued to the autopilot are both the same mechanisms in deriving the rate information are different. The IPPN setup an inner gamma-feedback loop to provide the indirect differentiation effect, while PPN use a direct differentiator. Consequently there is response to command discontinuity at handover.

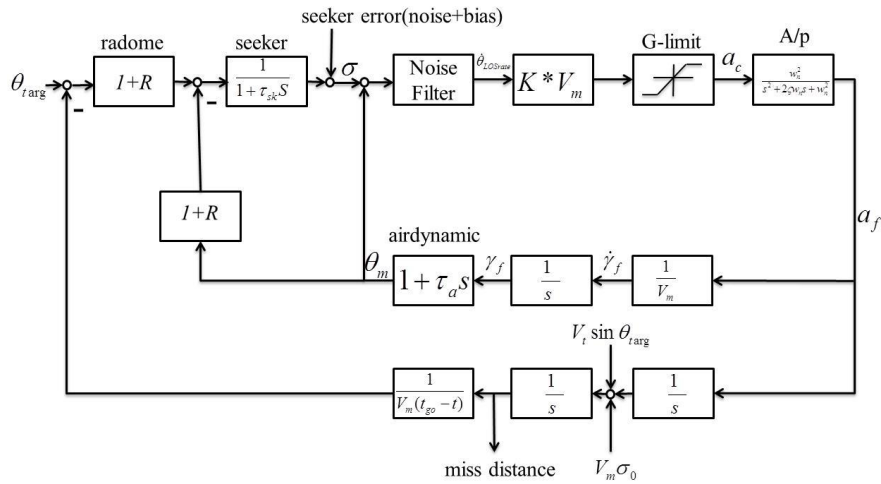


Fig.4. PPN guidance & control loop.

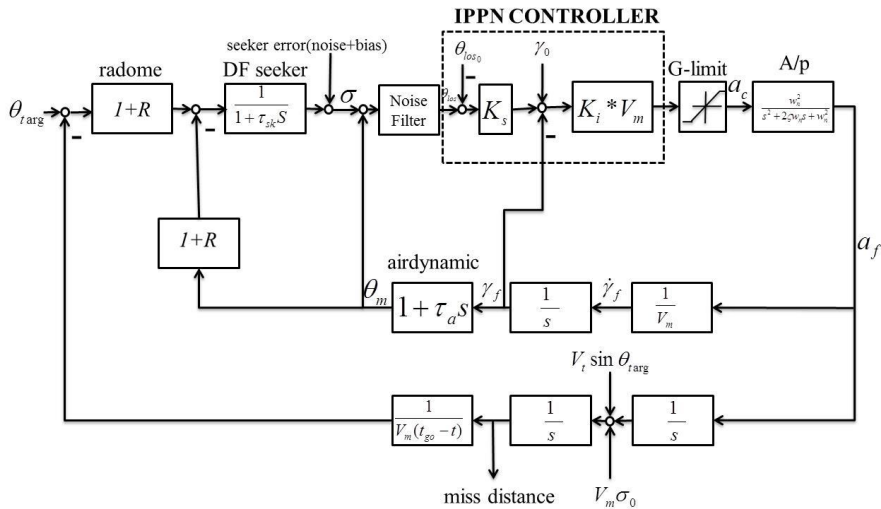
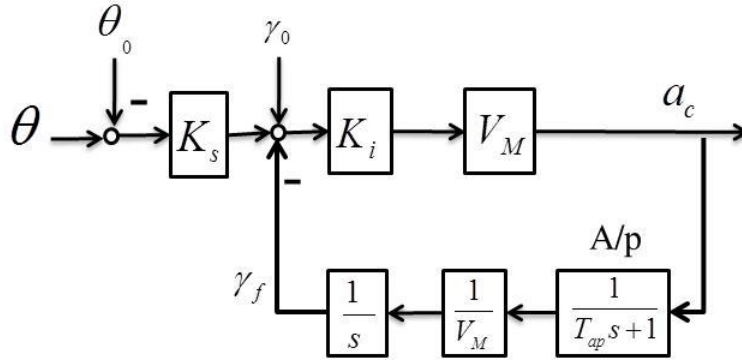
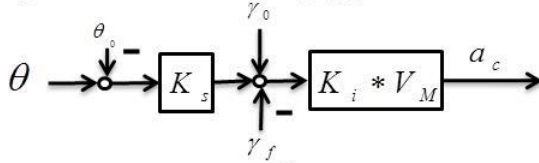
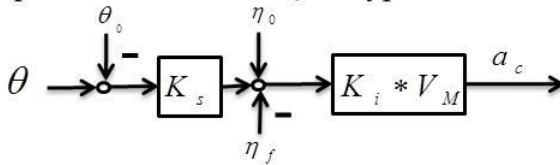


Fig.5. IPPN guidance & control loop.

## a) First-order autopilot Model

b) Equivalent Model-  $K_s$  typec) Equivalent Model-  $K_s$  -1 type

## d) Equivalent Model- N type

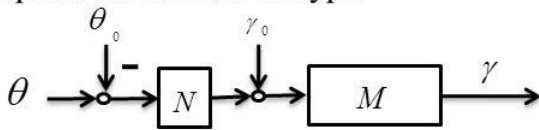


Fig.6. Simplified IPPN model.

## V. Simulation results

Through four simulation examples the ability of the IPPN to intercept the target of surface radar are illustrated, and the performance of trajectory shaping is shown. The initial conditions are as follows. For the non-maneuvering target,  $V_t$  is 10m/s. For the missile,  $V_m$  is 700m/s. In tail chase scenario, target initial position  $(X_{t0}, Z_{t0}) = (6000, 0)$  (M) and missile initial position  $(X_{m0}, Z_{m0}) = (0, 6000)$ . In head-on scenario,  $(X_{t0}, Z_{t0}) = (6000, 0)$  (M) and  $(X_{m0}, Z_{m0}) =$

$(12000, 6000)$ . The assumption is made that the missile can hit the target if the miss distance is less than 1 M. the hits are obtained in each of the simulation.

### 5.1 Trajectory profile sensitivity to gain

The missile motions in preliminary simulation are possible under two assumptions: neglecting the autopilot delay time and considering the action time approximately as a linearly shifted time. The nominate missile motions are expressed as:

$$V_m(k+1) = 0.5 \times [V_m(k) + V_m(k-1) + a_m(k)\Delta t] \quad (21)$$

$$R_m(k+1) = 0.5 \times [R_m(k) + R_m(k-1) + V_m(k)\Delta t] \quad (22)$$

where  $\Delta t$  is time update.

In bearing-only measurement, it supposes that  $\Delta t$  is 1 second. Figure 7~10 show the trajectory profiles for various navigation gain  $K_s$ ,  $K_i$ , and lead angle.

The nominal trajectory profiles are presented in Figure 7~10. It indicates a smooth lofting trajectory with flight path

always on one side of the target LOS, and a gradual cutting down of lead angle to zero. For slow-moving surface target, the IPPN produces predictable trajectory profiles, in which the guidance parameters that can be optimized to yield the desired path outcome are most likely: the lead angle and the flight path angle at handover; the navigation gain; and the bias command at initiation. An adjustable trajectory has been derived to represent these sensitivities.

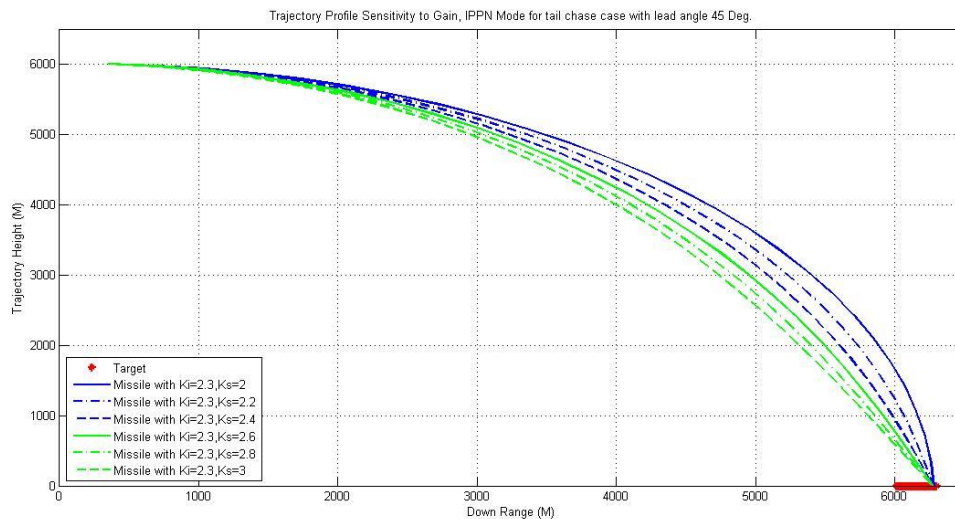


Fig. 7 Predicted trajectory profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim3$ , lead angle 45 Deg.

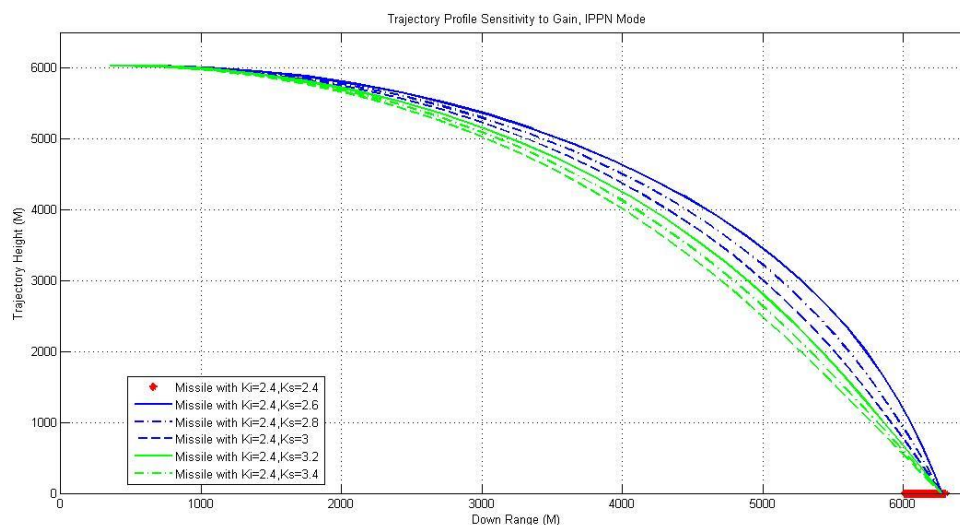


Fig. 8 Predicted trajectory profile sensitivity to gain,  $K_i=2.4$ ,  $K_s=2.4\sim3.4$ , lead angle 50 Deg.

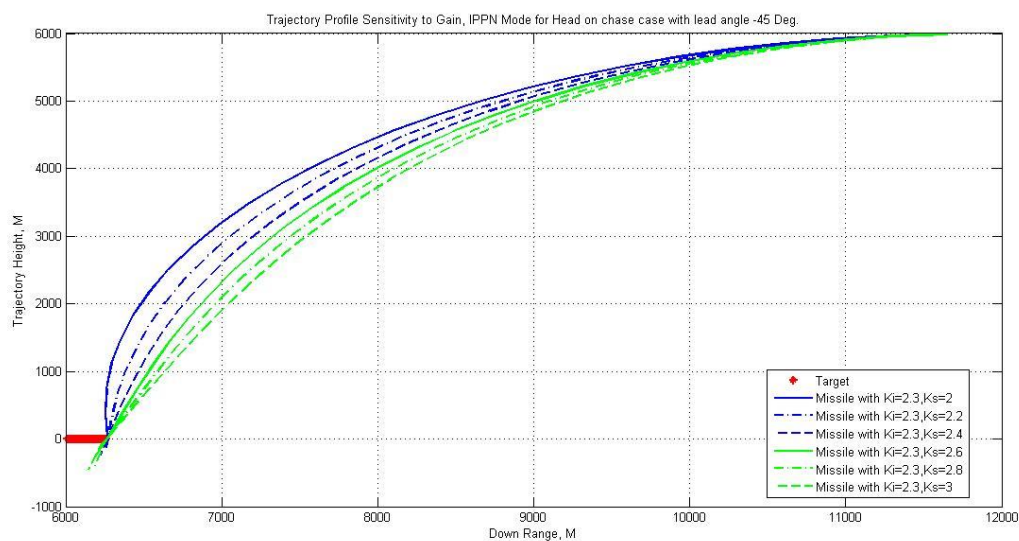


Fig. 9 Predicted trajectory profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim3$ , lead angle  $-45$  Deg.

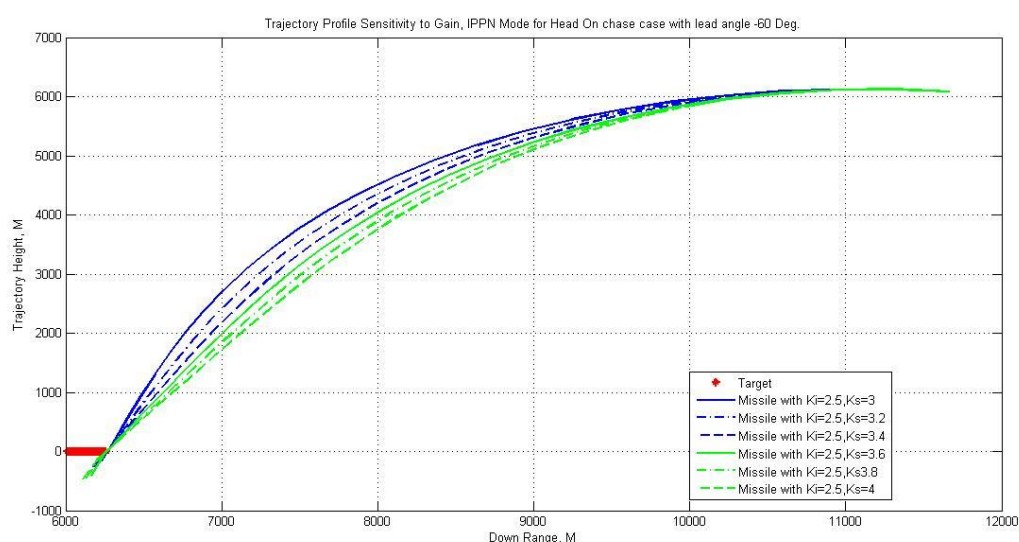


Fig. 10 Predicted trajectory profile sensitivity to gain,  $K_i=2.5$ ,  $K_s=3\sim4$ , lead angle  $-60$  Deg.

## 5.2 Hit angle sensitivity and prediction

The hit angle consequentially are dictated by: the scenario driving parameters, namely the lead angle (including head error), and the flight angle at handover; and the controlling parameter, the navigation gain, and the gama-bias command at ignition if any. The hit angle sensitivity to navigation gain  $K_s$  are shown in Fig. 11~14. Figures

show the hit angle history and the predicted values from simplified linear analysis. The hit angle becomes nearly vertical following a fast pitch-down at end. Parametrical sensitivities are obtained numerically for the nominal scenario. The basic controlling parameters are the navigation gain, the lead angle at handover, and the electronic gamma-bias command. The gains are utilized to yield desirable hit angle. The

IPPN can be optimized to yield predictable results at hit for terminal homing stage.

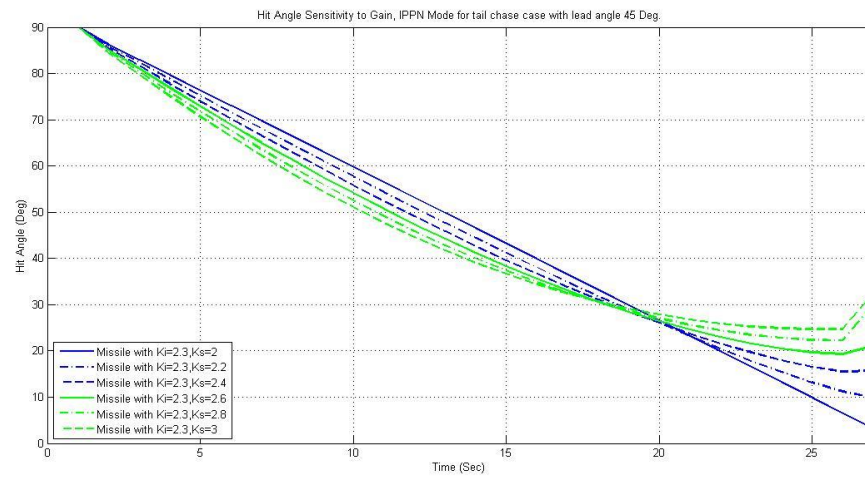


Fig. 11 Predicted hit angle profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim3$ , lead angle 45 Deg.

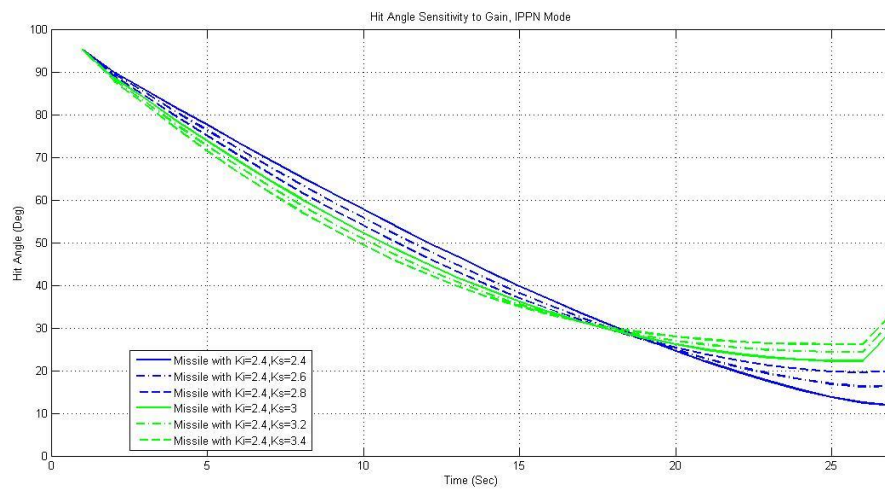


Fig. 12 Predicted hit angle profile sensitivity to gain,  $K_i=2.4$ ,  $K_s=2.4\sim3.4$ , lead angle 50 Deg.

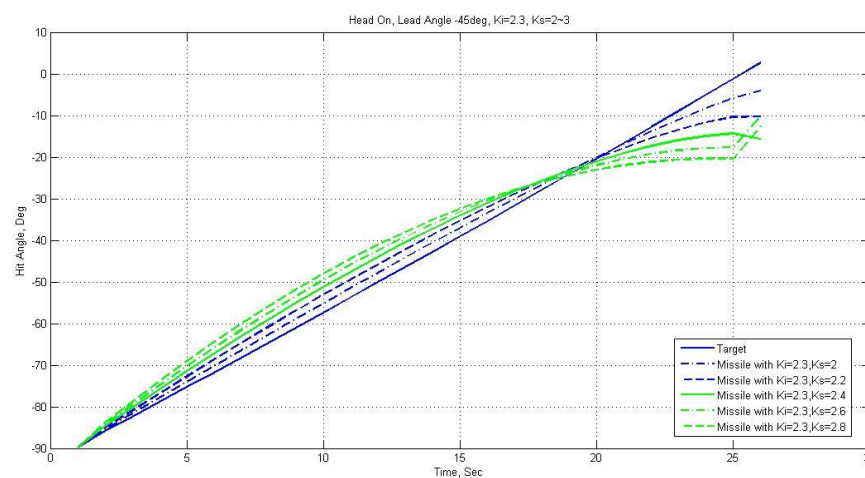


Fig. 13 Predicted hit angle profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim3$ , lead angle -45 Deg.

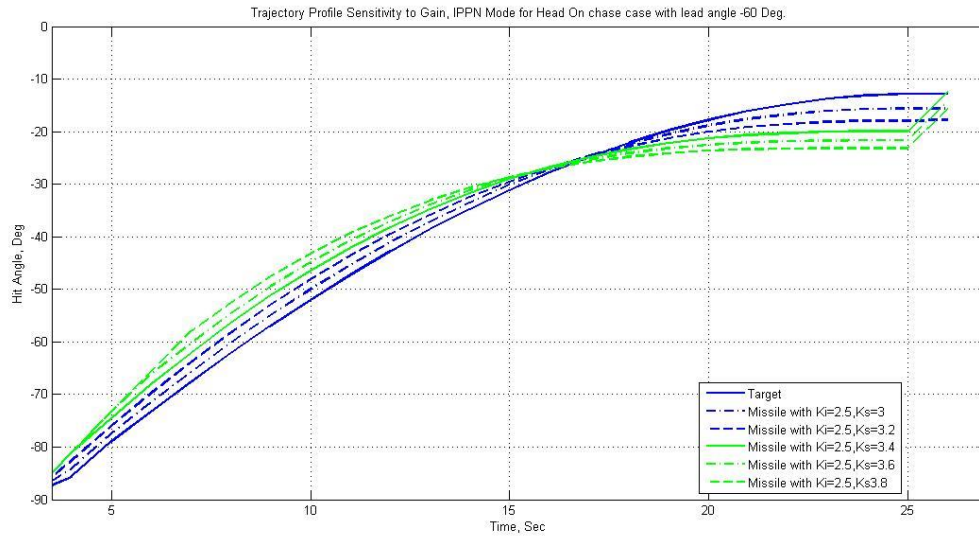


Fig. 14 Predicted hit angle profile sensitivity to gain,  $K_i=2.5$ ,  $K_s=3\sim 4$ , lead angle -60 Deg.

### 5.3 Low acceleration design

Design of non-saturating guidance law is considered. The illustrative examples validate the lower acceleration requirement and show that the IPPN guidance law is robust enough to guarantee even if realizable guidance system is somewhat loosened.

The missile lateral acceleration and sensitivity to navigation gain are shown in Fig. 15~18. The missile lateral accelerations in general are reducing to zero following an

initial rapid pitch-down transition. For  $K_s=2$ , the missile lateral acceleration remains constant. For  $K_s=3$ , the missile lateral acceleration linearly decreasing from a peak value to zero. The IPPN guidance therefore can be perceived as a missile lateral acceleration reducing scheme, with missile lateral acceleration reducing to zero at direct hit, and at a prescribed profile that can be controlled by gain. The missile lateral accelerations are always less than 15G for  $K_s$  less than 3.

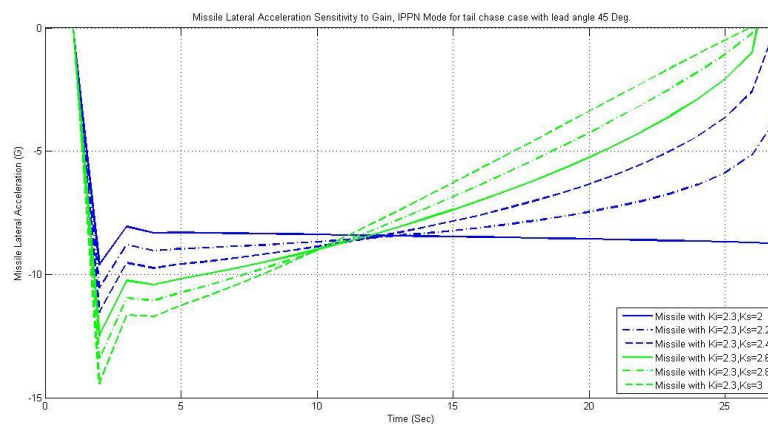


Fig. 15 Predicted missile lateral acceleration profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim 3$ , lead angle 45 Deg.

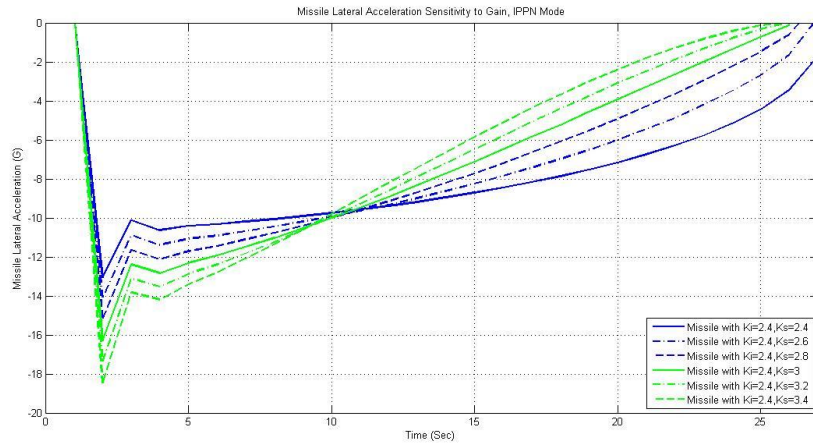


Fig. 16 Predicted missile lateral acceleration profile sensitivity to gain,  $K_i=2.4$ ,  $K_s=2.4\sim 3.4$ , lead angle 50 Deg.

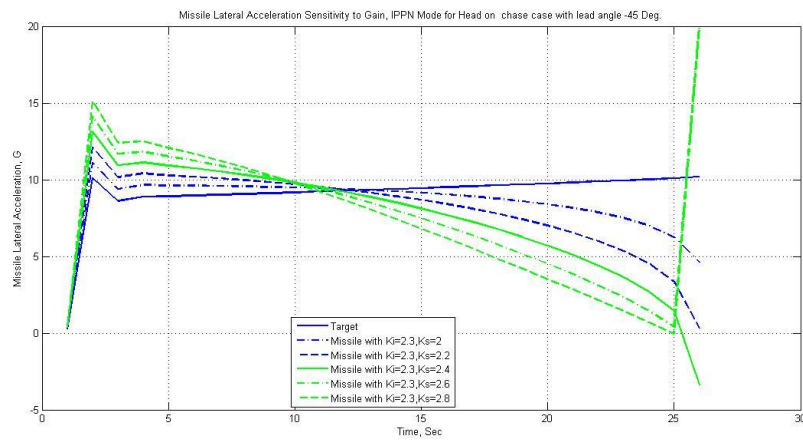


Fig. 17 Predicted missile lateral acceleration profile sensitivity to gain,  $K_i=2.3$ ,  $K_s=2\sim 3$ , lead angle -45 Deg.

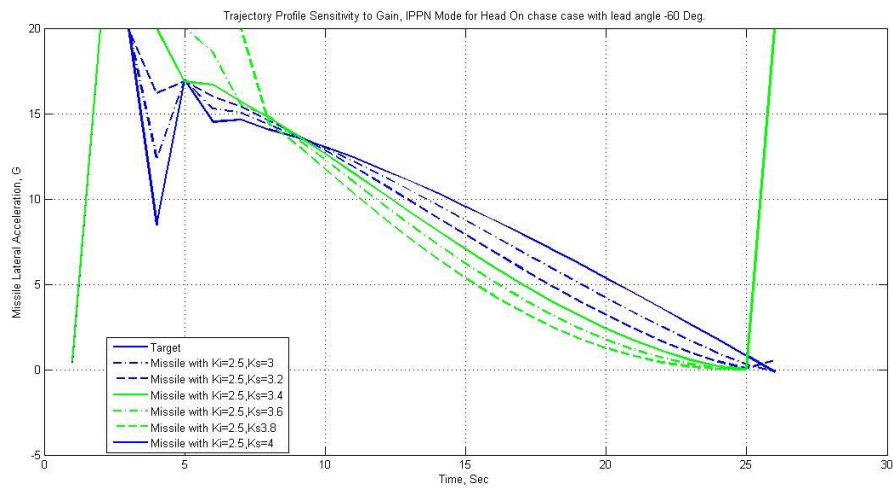


Fig. 18 Predicted missile lateral acceleration profile sensitivity to gain,  $K_i=2.5$ ,  $K_s=3\sim 4$ , lead angle -60 Deg.

## VI. Conclusion

The IPPN guidance scheme has been proved to be superior to the conventional PNG in response to LOS command for ARM. The IPPN, however, have one additional gain term and one additional summing joint. The additional freedom is utilized to yield desirable trajectory and hit angle outcome for terminal homing. The trajectory and hit angle sensitivities for these parameters are tabulated in simulation results indicate the IPPN produces less maneuvering near the end. For slow-moving surface target, the IPPN produces predictable trajectory profiles, in which the hit angle histories are predictable. Lower demands in missile acceleration at homing stage are desirable in improving ARM guidance law. The IPPN guidance scheme has been proved to be superior to the conventional PNG in response to LOS command for ARM. The IPPN, however, have one additional gain term and one additional summing joint. The additional freedom is utilized to yield desirable trajectory and hit angle outcome for terminal homing. The trajectory and hit angle sensitivities for these parameters are tabulated in simulation results indicate the IPPN produces less maneuvering near the end. For slow-moving surface target, the IPPN produces predictable trajectory profiles, in which the hit angle histories are predictable. Lower demands in missile acceleration at homing stage are desirable in improving ARM guidance law.

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## 反雷達飛彈之積分純比例導引律

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### 摘 要

本文研究積分比例導引律之優點，其導引迴路架構源自傳統比例導引，加以變化衍生。針對被動偵測慢速地(海)面目標，將積分比例導引理論工程實踐化得出之積分純比例導引律能夠產生可預測之拔高軌跡。積分純比例導引律僅允運用航向角及視向線角資訊產生導引命令，調整導引參數可獲得最適之軌跡與撞擊角度，其包括預置領先誤差角、航向角、導引迴路增益等。文中展示真實飛彈工程實踐時所得出之導引迴路圖，並有積分比例導引律、積分純比例導引律及積分真比例導引律之相關交戰場景模擬。

關鍵詞：導引律、比例導引、積分比例導引、積分純比例導引