**A New RF Stealth Performance Evaluation Method Based on PSCP**

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**Abstract.** A new RF (radio frequency) stealth performance evaluation method of electronic equipment based on polarization status changing parameter is presented. By analyzing typical intercept receiving mechanism in electronic war, a key factor - the uncertainty of radiating signals of electronic equipment is extracted from “radiating-intercepting” scenario. A calculating formula is established to transfer this kind of uncertainty to RF stealth factor. This RF stealth factor can be used to evaluate electronic equipments RF stealth performance directly, without relying on traditional complex “radiating-intercepting” scenario. Simulation results show the effectiveness of this evaluation method.

**Introduction**

With the development of electronic technology and wireless radiating technology, more and more electronic equipments are used in today’s war field and EW (electronic war) field, including airborne radar, ground based radar, IFF (identification friend or foe) radar, tactical data link, communication station, altimeter and other operational equipments [1-3]. In electronic war, both sides are willing to keep their own equipments normal operating and intercept/interfere adversary side’s equipments at the same time. RF stealth has become a challenging problem in electronic war field. The objective of stealth is to keep the adversary guessing until it is too late. Over the past few years, stealth platforms, especially aircraft, have come into public consciousness [1].

As RCS (radar cross section) is often used to measure targets stealth performance when illuminated by radar, a stealth factor is also needed to quantitatively measure the RF stealth capability of electronic equipment [4,5]. We call it RF stealth factor, indicating electronic equipment stealth ability under the premise of its own normal working [4]. The introduction of this factor has much help at the aspects of equipments design, equipments application and tactical design. For example, by changing airborne radar’s radiating signal waveform [6,7], or scanning mode from spatial sequential scanning to spatial random scanning[8,9], it’s RF stealth factor of airborne radar can be greatly decreased. This means that this airborne radar becomes harder to be detected/intercepted. As using electromagnetic wave to transfer energy and information, electronic equipment performance is often described by its operating parameters. Besides these parameters, its RF stealth factor is also needed to be used as a natural parameter to describe electronic equipment RF stealth performance.
In this paper, typical EW scenario and traditional RF stealth factor calculating methods are described in Section 2. In Section 3, a new RF stealth performance evaluation method based on PSCP is presented and its natural connotation is analyzed. Simulations are carried out to further describe this new method. Concluding remarks are given in Section 4.

**Traditional RF Stealth Performance Evaluation Method**

Suppose a typical EW scenario, an airborne radar is performing combat missions, while it's also under the surveillance of an adversary intercept receiver, as shown in Fig. 1.

![Figure 1. Typical Airborne Radar EW Scenario.](image)

In Fig. 1, $R_d$ and $R_i$ represent airborne radar detection range and EW receiver interception range, respectively. Two traditional methods, called IPC (intercepted probability characterization) and RRC (range ratio characterization), are often used to evaluate airborne radar RF stealth performance.

**IPC.** From the view of “radiating-intercepting” process, radar signal intercepted probability $P_i$ is often used to describe airborne radar RF stealth performance. This probability is determined by airborne radar operating parameters, such as peak power, waveform parameters and antenna gain [6].

(1) Peak power of transmit signal
The relationship of radar detecting range $R_d$, intercept distance $R_i$ and radar transmit signal peak power $R_t$ is given by

$$R_t \propto (P_i)^{\frac{1}{2}}, \quad R_i \propto (P_i)^{\frac{1}{4}}$$

This formula means that the bigger radar peak power, the worse of radar RF stealth.

(2) Waveform parameters of radar signal
The relationship of airborne radar bandwidth $B_r$, EW receiver $B_i$ and radar signal intercepted probability $P_i$ is shown below:

$$P_i \propto \left[ \frac{B_i}{(B_r)^2} \right]$$

With a larger radar bandwidth $B_r$, there will be a smaller intercept probability $P_i$. For a LFM (linear frequency modulation) radar with sweep time $T$ over bandwidth $B$, the instantaneous...
bandwidth during the frequency sweep is \( B_t = \left( \frac{B}{T} \right)^2 \), while that of a noise modulation continuous radar is \( B \). This means that LFM radar is more easily detected than noise modulation radar.

**RRC.** The ratio between EW receiver “one-way” interception range and airborne radar “two-way” detection range is often used to evaluate airborne radar RF stealth performance. Based on airborne radar detection mechanism and EW receiver interception mechanism, the ratio can be described as below [10]:

\[
\alpha = \frac{R}{R_e} = R_t \left( \frac{4\pi \cdot 1}{ \delta \cdot \sigma \cdot G_t G_r \cdot L_r} \right)^{\frac{1}{2}}
\]

(3)

where \( \delta \) is the ratio of signal power required at the EW receiver to that required at the airborne radar receiver; \( \sigma \) is the RCS of target; \( G_t \) is the gain of airborne radar transmit antenna towards EW receiver; \( G_r \) is the gain of EW receiver antenna towards airborne radar; \( G_t \) is the gain of airborne radar transmit antenna towards target; \( G_r \) is the gain of airborne radar receiver antenna towards target, \( L_t \) and \( L_e \) are losses in the airborne radar and EW receiver respectively. In case of \( \alpha < 1 \), it means that EW intercept range is smaller than airborne radar detection range. If \( \alpha > 1 \), it means that airborne radar is easy to be intercepted.

Both IPC and RRC are easy to understand, but hard to be realized. An air combat scenario, including both sides fighters and EW aircrafts needs to be established. Based on this scenario, radar signal intercepted probability \( i \) and the ratio between EW receiver intercept range and airborne radar detection range \( \alpha \) can be obtained under the assumption of known operation parameters of both airborne radar and EW receiver. It’s easy to be found that the two evaluation methods are difficult to be used at the aspect of RF stealth performance evaluation. EW receiver operation parameters, such as mainlobe width, level of sensitivity, also affect airborne radar RF stealth performance evaluation result [6,10-11]. Furthermore, radio frequency range also has influence on RF stealth [11].

In fact, like peak power, main lobe width, bandwidth and other operating parameters, RF stealth parameter is one of intrinsic operating parameters of airborne radar. It’s determined only by airborne radar radiating signal parameters. New RF stealth performance evaluation method needs to be introduced to replace traditional evaluation method.

**RF Stealth Performance Evaluation Method Based on PSCP**

**Separate Field Division.** From the view of electromagnetic radiation propagation theory, airborne radar RF stealth can be divided into simple detection problem in different fields. Suppose airborne radar radiation electric field at EW receiver location is

\[
E_i(t) = \hat{E}(t) \sum_{n=0}^{\infty} A_r \text{rect} \left( \frac{t - nT}{T_r} \right) \cos(2\pi f_{f,i}t + \phi)
\]

(4)
where \( \hat{E}(t) \) represents electric field time-variable polarization status, \( A_n \) represents \( n \)th pulse amplitude,
\[
\text{rect}\left(\frac{t}{T_p}\right) = \begin{cases} 1.0 & 0 < t < T_p, \\ 0, & \text{otherwise} \end{cases}
\]
represents rectangle function, \( T_r \) represents PRF(pulse repetition frequency), \( T_p \) represents radar pulse width, \( f_0 \) represents radar carrier wave frequency, \( \phi \) represents radar carrier wave phase. How hard this signal can be detected and intercepted by adversary EW receiver determines the level of this airborne radar RF stealth performance.

As the operating parameters of radar radiation signal are often unknown to EW receiver, EW receiver needs relative long time coherent accumulation to achieve effective intercept. From (4), the coherent accumulation process can be divided into three separate accumulation in polarization field, energy field and waveform field, as shown in Fig. 2.

![Figure 2. RF Stealth Performance Divided into Three Separate Fields.](image)

In Fig. 2, \( \sum(\cdot) \) means relative long time accumulation operation, \( f_p(\cdot) \), \( f_e(\cdot) \) and \( f_w(\cdot) \) means polarization transfer function, energy transfer function and waveform transfer function.

**Polarization Field Evaluation Based on PSCP.** EW receiver often needs relative long time coherent accumulation to achieve effective intercept. Three situations are discussed below.

1. **Constant polarization status**
   Airborne radar radiates constant linear polarization or circular polarization electric field. In this simplest case, we believe that EW receiver can intercept radar signal one hundred percent. Based on constant polarization status, \( f_p[\hat{E}(t)] \) can be added coherently at each time \( t \) and the accumulation makes radar signal can be easily intercepted by EW receiver.

2. **Regularly changing polarization status**
   If airborne radar changes its electric field polarization status from H(horizontal) status to \( V(\text{vertical}) \) status, or from RHCP(right hand circular polarization) to LHCP(left hand circular polarization) once per \( T_p \) seconds, EW receiver is required to be able to keep up with this change with the same frequency. Otherwise, \( \sum(\cdot) \) will decrease the accumulation effect and cause polarization attenuation. As a result, radar signal will be more difficult to be detected.

3. **Random changing polarization status**
   If airborne radar changes its electric field polarization status randomly, EW receiver will not able to keep up with this change. It’s RF stealth performance is best.
From the above analysis, we can found that airborne radar RF stealth performance has a strong correlation with radar signal polarization changing parameter. Let $\sigma_p$ represents airborne radar RF stealth factor, $T_p$ represents radar signal polarization changing cycle. Define the range of $\sigma_p$ is $[0, 1]$. $\sigma_p = 0$ means that radar has best RF stealth performance, while $\sigma_p = 1$ means that radar has worst RF stealth performance. $T_p = 0$ means that radar radiates constant polarization electric field, corresponds to $\sigma_p = 1$. While $T_p \to \infty$ means that radar radiates random polarization electric field, corresponds to $\sigma_p = 0$. With the increase of $T_p$, it’s RF stealth performance becomes better and it becomes harder for adversary EW receiver to carry out effective detection and interception. Fig. 3 shows the contrast of constant polarization and random polarization.

![Figure 3. Different Polarization Status.](image)

To achieve quantitative assessment of airborne radar RF stealth performance, a new method based on PSCP is presented and the calculating formula is shown below:

$$\sigma_p = 1 - \frac{2}{\pi} \arctan T_p$$

(5)

The relationship between radar signal polarization changing cycle $T_p$ and radar RF stealth factor in polarization field $\sigma_p$ can be described in Fig. 4.

![Figure 4. $T_p$-$\sigma_p$ Curve.](image)
As shown in Fig. 3(a), radar signal polarization status keeps constant linear, $T_p = 0$, thus $\sigma_p = 1$ by using (5). In Fig. 3(b), radar signal polarization status changes randomly, $T_p \to \infty$, RF stealth factor $\sigma \to 0$. If radar signal polarization status changes once per 1 second, $\sigma_p = 0.5$.

The new RF stealth performance method is easy to be realized and integrated into other RF stealth factors so as to achieve multi-fields joint assessment.

**Concluding Remarks**

In this paper, a new RF stealth performance evaluation method of electronic system in polarization field is presented. By extracting the polarization changing parameter of electronic equipment/system, a RF stealth factor formula is established and the RF stealth performance can be evaluated quantitatively. Compared with other existing performance evaluation methods, this new method can be used to obtain electronic equipment RF stealth factor directly from its radiating parameters, without relying on traditional complex “radiating-intercepting” scenario. Simulation results show the effectiveness of the proposed method. Future work will focus on multi-fields joint evaluation.

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**References**


