On SCR of PCL AEW Utilizing FM Illuminators

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Introduction

Radar is now playing a more and more important role in modern high-technology war, but it is also faced with the crucial anti-radar circumstances[1-3]. Passive radar utilizing radiation from other illuminators has emerged in the last decade. The most typical systems for them may be 'Silent Sentry'[4] system designed by Lockheed corp. Here our main focus lies in PCL[5, 6] radar. Just as airborne early warning radar is just lifting the radar to a higher elevation of aircraft, with the rapid development of PCL, it is easy to deduce a PCL AEW system which should be more powerful than either of themselves.

PCL AEW Principle

The airborne PCL radar detects and locates the targets such as aircraft utilizing the scattering and reflecting echoes from the targets as well as the direct radiation reference signals from the illuminators. These two signals are usually respectively received by two sets of antenna or antenna array and the following receiving channels and then are fed to coherent location processing[7]. The targets in the ovals centered around the transmitter or the PCL receiver can be monitored and tracked, furthermore the distance, velocity and azimuth information, even type and model information about the targets can be obtained by means of array signal processing and data fusion technologies. It can make full use of AEW's large coverage and PCL radar's passive and silent advantages at the same time, so as to play an important role in future civil and military application. A PCL AEW radar system configuration and signal skeleton diagram can be illustrated as Fig.1, which mainly consists of illuminator transmitter, target of interest, PCL AEW radar receiver terminal and processing equipment. Similar to the ordinary PCL radar, the key problem in the PCL AEW radar system designing lies in the signal model of analyzing the target signal to clutter or interference signal ratio SCR under the new system configuration.

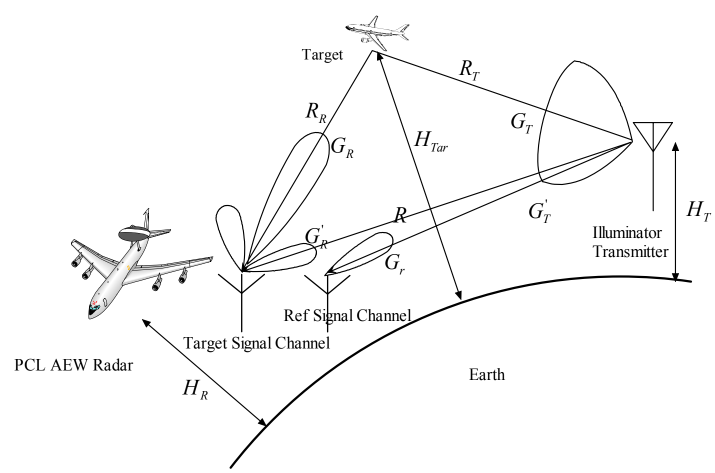

Fig.1 PCL AEW radar system

Signal Model

Target reflected signal received from the main lobe at the target channel $y(t)$ can be formulated as[3]

$$P_y = \frac{P_T G_T F_T^2}{4\pi L_{p_T} R_T^2} \cdot \frac{\sigma_T F_R^2}{4\pi L_{p_R} R_R^2} \cdot \frac{G_R \lambda^2}{4\pi} = \frac{P_T G_T G_R F_T^2 F_R^2 \lambda^2 \sigma_T}{(4\pi)^3 L_{p_T} L_{p_R} \left(R_T R_R\right)^2} \cdot \quad (1)$$

The expected target signal to noise ratio SNR is as follows

$$SNR = \frac{P_y}{P_n} = \frac{P_T G_T G_R F_T^2 F_R^2 \lambda^2 \sigma_T}{(4\pi)^3 L_{p_T} L_{p_R} K_0 T_s B_n \left(R_T R_R\right)^2} \quad (2)$$

While the harmful directly arrived signal leakage component into the side lobe of the target channel $y'(t)$ can be expressed as following formula

$$P_{y'} = \frac{P_T G_T^{'}}{4\pi L_{p_T} R^2} \cdot F_{Tr}^2 \cdot \frac{G_R^{'} \lambda^2}{4\pi L_{p_R}} = \frac{P_T G_T^{'} G_R^{'} F_{Tr}^2 \lambda^2}{(4\pi)^2 L_{p_T} L_{p_R} R^2} \cdot \quad (3)$$

As most illuminators such as FM broadcast radiate signals isotropically in their horizontal radiation pattern, while they will compress most of their radiation energy on horizontal plane of most users' location. To analyze the critical factor of SCR for passive radar, the vertical radiation pattern for FM broadcast and the corresponding elevation angle for target or AEW were derived, with the aid of bistatic radar equation, the SCR for this novel passive radar system was obtained and simulated numerically under a reasonable reality circumstance.

FM Radiation Pattern

In general FM broadcast adopts dipole antenna or several dipole elements installed vertically to form sharp or high gain beam at horizontal plane. Here we study a commercial FM broadcast with radiation power of 8kw and four dipole elements spaced $d=3\lambda/4$ installed at the top of 130m tower. The total vertical radiation pattern function for linear uniformly array consisting of N dipole elements spaced d can be written as

$$f(\varphi) = f_1(\varphi) \cdot f_2(\varphi) = \frac{\cos(\frac{pi}{2}\cos\varphi)}{\sin\varphi} \cdot \frac{\sin\frac{N\beta}{2}}{N \cdot \sin\frac{\beta}{2}} \cdot \quad (4)$$

The vertical radiation pattern for our example can be simulated and plotted in the following Fig.2.

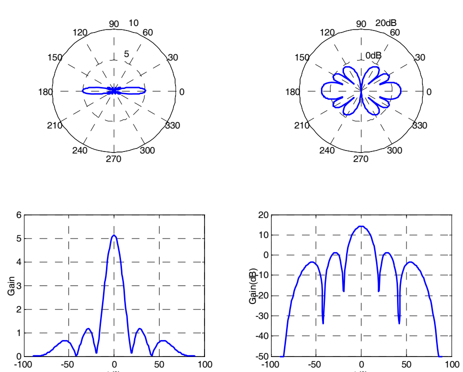

Fig.2 Vertical radiation pattern for a FM LUA.

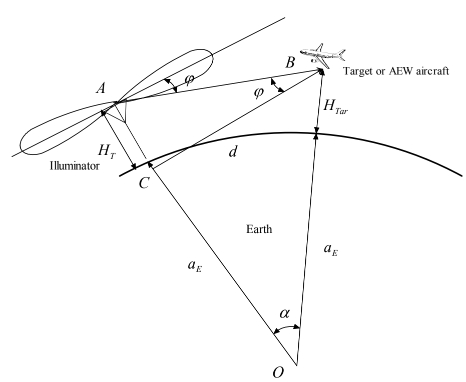

Fig.3 Elevation angle towards FM antenna

SCR

The target signal-to-clutter ratio SCR can be simplified as

$$SCR = \frac{P_y}{P_{y'}} = \frac{1}{4\pi} \cdot \frac{\sigma_T R^2}{\left(R_T R_R\right)^2} \cdot \frac{G_T G_R}{G_T^{'} G_R^{'}} \tag{5}$$

The horizontal radiation pattern for FM broadcast is generally isotropic and its influence on target and AEW receiver are of the same and can be cancelled. Here we mainly take into account vertically elevation angle's gain introduced by target and AEW aircraft's location and height. Target or AEW aircraft's elevation angle towards FM antenna center can be depicted in Fig.3.

Elevation angel can be calculated by the following formula

$$\varphi = \operatorname{arctg}\frac{\Delta H}{d'} = \operatorname{arctg}\frac{(a_E + H_T) - (a_E + H_{Tar})\cos(\arcsin(\frac{d}{a_E}))}{(a_E + H_{Tar})\sin(\arcsin(\frac{d}{a_E}))} \tag{6}$$

Once we get the elevation angle of target or AEW aircraft, we can obtain their transmit radiation gain from the FM broadcast by replacing the corresponding elevation angle in the radiation pattern. Then if the main and side lobe ratio for the target receiver channel's antenna is known, we can calculate the final reasonable SCR.

$$SCR = \frac{P_y}{P_{y'}} = \frac{1}{4\pi} \cdot \frac{\sigma_T R^2}{\left(R_T R_R\right)^2} \cdot \frac{G_T\left(H_{Tar}, H_T, R_T\right) G_R\left(H_{Tar}, H_R, R_R\right)}{G_T^{'}\left(H_T, H_R, R\right) G_R^{'}\left(H_T, H_R, R\right)} \tag{7}$$

Where H_T, H_R, H_{Tar} denotes the height of FM broadcast antenna array, AEW aircraft and target respectively.

Simulation Results

Here we analyze three typically cases of target's location in the bistatic passive radar as Fig.4 shown.

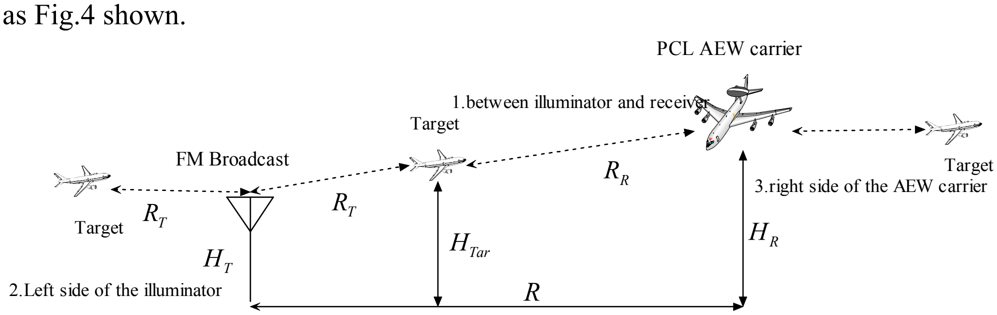

Fig.4 Three typical cases for target location in the PCL AEW system

It is assumed that a target with the RCS of σ_T at the height of 50m、100m、200m、1000m and up to 8000m flying from faraway than the FM station towards the PCL AEW receiver. The AEW aircraft flying at the height of 8000m at the distance of 200km away from the FM station. Furthermore it is assumed that the main and side lobe ratio $G_R/G_R^{'}$ for the target receiver channel's antenna is 1. The SCR for target with the RCS of 1m^2、10m^2 和 100m^2 at different location and height can be numerically simulated as Fig.5.

Conclusions

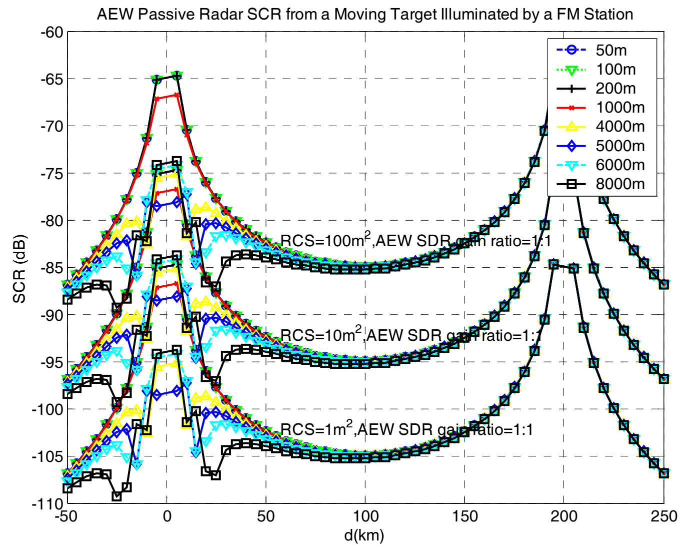

Fig.5 SCR for target with different RCS at different location and height

The concept of Passive Coherent Location AEW radar system utilizing illuminators of opportunity such as commercial FM broadcast was presented firstly, followed by its system description and characteristics analysis, especially its signal model and SCR simulation. Finally, from our analysis and simulation results, it is come to a conclusion that a reasonable SCR lies in the range of -60~-110dB for a reasonable target with a proper height and distance from the bistatic radar's illuminator and the receiver. At the same time, constant SCR holds for an oval of Cassini just as the SNR does for bistatic radar. Furthermore, the SCR distribution appears in a symmetric way around the FM broadcast or the PCL AEW receiver. It is expected that some day PCL AEW must come into true.

References:

[1] Volker Koch, Robert Westphal. A new approach to multistatic passive radar sensor for air denfense[C]. IEEE Radar Conference. 1995. p. 22-28.

[2] Wang Jun, Zhang Shouhong and Bao Zheng. Passive Coherent Detecting via Exploiting Illuminator of Opportunity[C]. Proceeding of International Conf on Signal Processing. August 2002. Beijing. p. 1415-1418.

[3] Skolnik, M I, Radar Handbook[M]. 2003, Peking: PHEI.

[4] J Baniak, G BakerAnn, M Cunningham, L Martin., Silent SentryTM Passive Surveillance[EB/OL], http://www.dtic.mil/ndia/jaws/sentry.pdf

[5] Zhou, Chucai Cliff, Application and extension of space-time adaptive processing to passive FM radar [D]. 2003.Univ. of Washington.

[6] Sahr, John. The 3rd multi-national conference passive and covert radar[C]. 2003, University of Washington.

[7] Frazer, Maurice A. Ringer and Gordon J. Waveform Analysis of Transmissions of Opportunity for Passive Radar[C]. ISSPA '99. 22-25 August, 1999. Brisbane, Australia. p. 511-514.