

ES detection range model of circular scan radars

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Abstract: The signal power received at an ES(Electronic warfare Support) system varies over the time due to the scan characteristics of radar, which results in the ES detection range. This paper analyzes the ES detection range for the circular scan and proposes a model to evaluate it quantitatively. Experimental results using real radars demonstrate that the proposed model is suitable for the evaluation of the ES detection range related with the circular scan of radars.

1. Introduction

In general, ES involves receiving enemy signals to identify and locate threat emitters and to help determine the enemy's force structure and deployment. Its primary functions are detection of threat signals, identification of threat types and operating modes, location of threat emitters, display or handoff of threat information to support situation awareness[1]. In ES systems, detection range relates with receiver sensitivity and it is considerable factor for the identifying threat and finding threat location.

An ES system intercepts signals emitted by radars, and detects the presence of radars by means of extracting each pulse trains composed of several pulses in the intercepted signals[2],[3]. In designing an ES system, the ES range equation may be applied in determining the receiver sensitivity and evaluating its performance. For the simplicity of system design, it is assumed that the signals received by an ES system are transmitted at the peak of a radar antenna pattern and only the antenna polarization loss between the radar and the ES system is considered in the ES range equation[4]. Assuming tracking radar that utilizes pulse signal is in the track of the platform with an ES system, the radar signal received by the ES system is virtually constant in power because all of the received signals are from the peak of the radar antenna pattern. In case of search radar, however, the received signal power varies between pulses since it continuously scans over the space in order to find targets.

Consequently, the signal power in the ES system depends on the antenna pattern and the scan characteristics of search radar, which results in ES detection range. As the antenna pattern loss[5]-[8] is considered in the radar equation for search radars, the ES detection range according to the signal power variation should be similarly included in the ES range equation. This paper presents the model and analysis of the ES detection range associated with the circular scan that is one of the most popular scan types of search radars.

2. Signal Power at ES System

In general, the radar signal power received by the ES system is written as the following[4]:

$$P_r = \frac{P_t G_t G_r \lambda^2}{16\pi^2 R^2 L_{TX} L_p} \quad (1)$$

Where P_t is a transmitter power, λ is the wavelength, G_t is the gain of the radar antenna, G_r is the gain of the ES antenna, R is the distance between the ES system and the radar, L_{TX} is the transmission loss of a radar, and L_p is a polarization loss between radar and ES system.

From equation (1), the maximum detection range of the ES system can be written as the following[4]:

$$R = \left[\frac{P_t G_t G_r \lambda^2}{16\pi^2 s_0 L_{TX} L_p} \right]^{\frac{1}{2}} \quad (2)$$

where s_0 is the sensitivity of the ES system.

In equation (1), it is assumed that the radar's antenna bore-sight is equal to the direction to ES system. A search radar performs spatial scanning by changing the radar's antenna bore-sight to detect targets. Consequently the received signal power in the ES system varies over the time and its modulation pattern depends on the radar's antenna beam pattern and the scan characteristics.

For a circular scan radar, if L_{TX} and L_p in (1) are not considered, the received signal power in the ES system can be written as the following:

$$P_r(\theta) = \frac{P_t G_t G_r \lambda^2}{16\pi^2 R^2} g_t(\theta) = P_0 g_t(\theta) \quad (3)$$

where θ is the azimuth offset angle between the radar's antenna bore-sight and the direction to ES system, and $g_t(\theta)$ is the normalized radar antenna pattern.

If the radar has a circular scan period of T_s , θ changes over the time, and the relationship can be related as $\theta = (2\pi t / T_s)$. By substituting this relation into (3), the received signal power can be obtained as in (4), where ω_s implies a scanning angular frequency and θ_0 corresponds to the initial azimuth angle. This received power variation depends on $g_t(\theta)$ and ω_s :

$$P_r(t) = P_0 g_t(\omega_s t + \theta_0), \quad \omega_s = \frac{2\pi}{T_s} \quad (4)$$

In Fig. 1, the time interval T_B to the point of the half power of the peak P_0 can be defined as (θ_B/ω_s) and is proportional to 3dB beam width θ_B and scan period T_s . The number of pulses N_B in T_B is defined as the following[5]:

$$N_B = \frac{\theta_B}{\omega_s T_p} \quad (5)$$

where T_p is the pulse repetition interval of the radar.

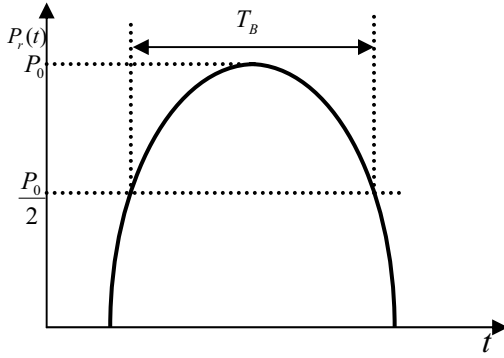


Figure 1. Main beam pattern of a circular scan radar at the input of an ES system.

3. Loss Model for ES Detection Range

For an ES system to detect a radar, it should receive at least N_r pulses which are the minimum number of pulses required for detecting the activity of radars[9][10]. If N_r is equal to N_B , there is 3dB loss compared with the case of constant power P_0 . Obviously the larger N_r is, the greater the loss becomes. In this paper, this loss related with the circular scan is referred to as the ES detection loss L_s . This L_s is defined as the ratio of P_r for $\theta=0$ in (1) to the smallest signal power in N_r . The smallest signal power can be derived from the beam width θ_r corresponding to N_r . This θ_r is referred to as the required beam width for radar detection and can be written as (6) using (5):

$$\theta_r = \omega_s T_p N_r \quad (6)$$

By the symmetry of antenna beam pattern, the smallest signal power P_r is obtained when θ is equal to $\theta_r/2$ in (3). Then L_s is given as the following:

$$L_s = \frac{P_r(0)}{P_r(\theta_r/2)} = \frac{P_0}{P_0 g_t(\theta_r/2)} = \frac{1}{g_t(\theta_r/2)} \quad (7)$$

Consequently, for the circular scanning radar, the conventional ES range equation (1) should be changed as the following:

$$R = \left[\frac{P_t G_t G_r \lambda^2}{16\pi^2 s_0 L_{TX} L_p L_s} \right]^{\frac{1}{2}} \quad (8)$$

It is necessary to introduce a representative model of radar antenna pattern $g_t(\theta)$ for quantitative evaluation of L_s . In general, circular scan radars use fan beam antennas such as a parabolic cylindrical reflector antenna, whose radiation pattern is similar to the pattern produced by the n-th power of the cosine current distribution among the well-known analytical models[11]. The side lobe level of circular scan radars is commonly less than -30dB in military application purposes. Using the antenna pattern[11] as in (9) produced by the cosine-squared current distribution with -31.5dB side lobe level, L_s is presented as in (10):

$$g_t(\theta) = \left[\frac{\pi^2 \sin(u)}{(\pi^2 - u^2)u} \right]^2, \quad u = \left(\frac{4.56}{\theta_B} \right) \sin(\theta) \quad (9)$$

$$L_s = \left[\frac{(\pi^2 - u^2)u}{\pi^2 \sin(u)} \right]^2, \quad u = \left(\frac{4.56}{\theta_B} \right) \sin\left(\frac{\theta_r}{2}\right) \quad (10)$$

Since θ_r is so small that $\sin(\theta_r/2)$ can be replaced by $\theta_r/2$, (10) can be approximated into (11), where r_θ is the ratio of 3dB beam width of the radar antenna to the required beam width for an ES system to detect this radar:

$$L_s \cong \left[\frac{2.28\pi^2 r_\theta - (2.28)^3 r_\theta^3}{\pi^2 \sin(2.28r_\theta)} \right]^2, \quad r_\theta = \frac{\theta_r}{\theta_B} \quad (11)$$

Fig. 2 is the simulation results from the proposed model to evaluate L_s quantitatively. When the 3dB beam width of the radar antenna is equal to the required beam width for detecting the presence of radar(or r_θ is equal to one in short), as shown in Fig. 2, L_s becomes 3dB just as the theoretical analysis result predicts.

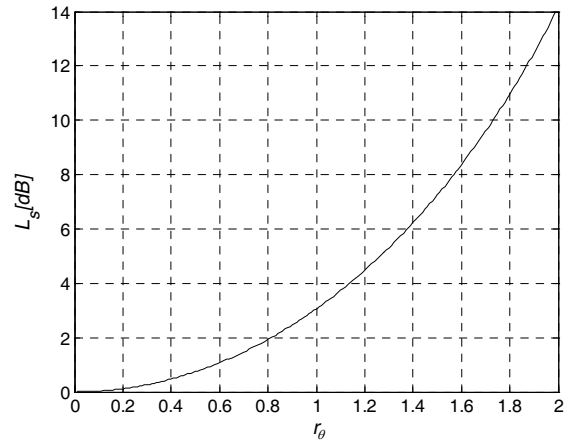


Figure 2. ES detection loss related with the circular scan.

Under the assumption of $N_r=10$, for instance, a circular scan radar with the operational parameters of $\theta_B=1^\circ$, $T_s=2\text{sec}$ and $T_p=450\ \mu\text{s}$ will yield 0.81 of r_θ . As shown in Fig. 2, L_s is approximately equal to 2dB and the ES detection range reduces to 0.8. If T_p is doubled for long-range search, r_θ becomes doubled, L_s is approximately 8.5dB, and the ES detection range gets approximately a half of that of short-range search.

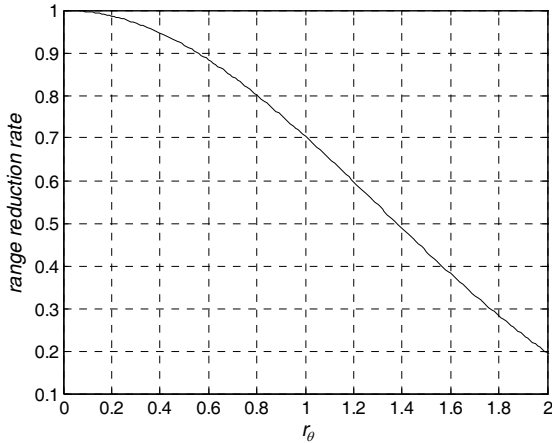


Figure 3. ES detection range related with circular scan.

4. Experimental Results

Signal power arriving at an ES system from real radars was measured to verify the validity of proposed model. Radar signals were collected using the ES receiver that comprises an omni-directional antenna and signal processing unit with the resolution of 0.3125dB in power and 50ns in time. All the radars used in this experiment are circular scan radars. Their specifications are listed in table 1. Setting $N_r=10$, L_s calculated by the proposed model for each radar is presented in table 1.

Table 1. Specifications of real radars and L_s is calculated using the proposed model with $N_r=10$.

Radar	Parameters			Calculated L_s [dB]	Measured L_s [dB]
	θ_B [°]	T_s [sec]	T_p [sec]		
A	1.1	2.5	1/4000	0.32	0.35
B	0.7	1.82	1/3600	1.86	1.52
C	1.4	1.0	1/3600	1.53	1.67

In the experiment, the signal powers measured in real-time base are normalized in the first hand. And L_s is evaluated by calculating the ratio of maximum to minimum power of N_r pulses that form the main beam. The received signal powers for each radar are shown in Fig. 3 where the horizontal axis corresponds to the pulse arrival time.

L_s 's in Fig. 3 are 0.31dB and 1.24dB for Radar A and B,

respectively. For Radar C, L_s is 1.56dB. The same experimental procedures related with the ES detection loss calculation are repeated for 10 times for each radar, and the results and the averaged values are listed in table 2.

A comparison of the measured losses in table 2 and the calculated losses by the proposed model in table 1 tells no significant deviation.

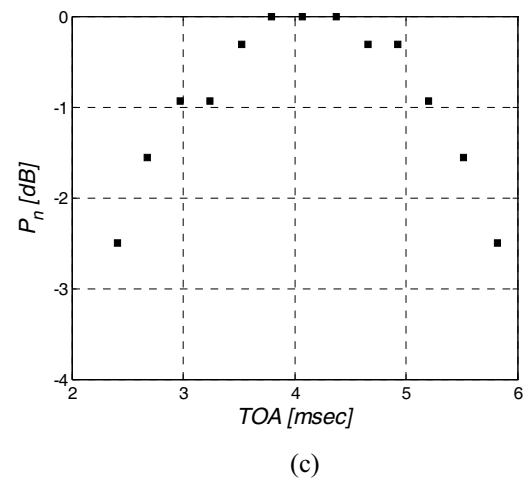
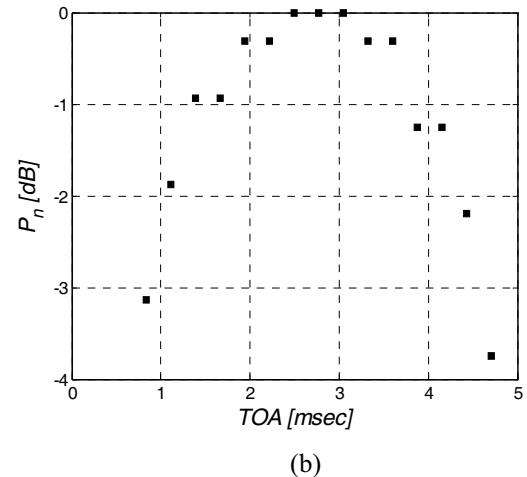
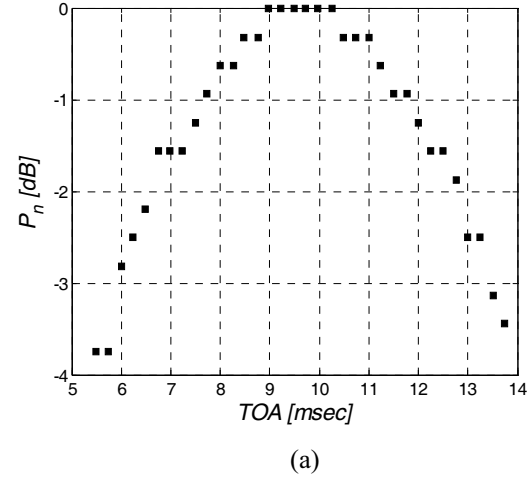


Figure 4. Normalized signal powers measured by the ES system. (a) radar A, (b) radar B, (c) radar C

Table 2. Measured loss L_s for real radars with $N_r=10$

No.	Measured L_s [dB]		
	Radar A	Radar B	Radar C
1	0.31	1.24	1.56
2	0.63	1.56	1.56
3	0.31	1.56	1.56
4	0.31	1.56	1.56
5	0.63	1.24	1.56
6	0.31	1.24	1.88
7	0.31	1.88	1.88
8	0.31	1.88	1.88
9	0.00	1.56	1.56
10	0.31	1.56	1.88
average	0.35	1.52	1.67

5. Conclusions

For the search radars, the detection range should be considered in the ES range equation since the pulse amplitude arriving at ES system varies over the pulses. In this paper, a theoretical analysis of ES detection range for circular scan radar is performed, and a model for quantitative performance estimation is proposed. In the experiment, the detection range of real radars is measured and compared with the calculated loss to show the correspondence of model. The proposed model is expected to be applicable in EW systems design, modeling and performance evaluation.

References

- [1] David L. Adamy, *Introduction to Electronic Warfare Modeling and Simulation*, Artech House, pp.83-95, 2003.
- [2] David Adamy, *EW101 : A First Course in Electronic Warfare*, Artech House, pp.3-5, 2001.
- [3] J. A. V. Rogers, "ESM processor system for high pulse density radar environments," *IEE Proceedings*, Vol.132, Pt. F, No.7, pp.621-625, Dec. 1985.
- [4] Filippo Neri, *Introduction to Electronic Defense Systems*, Artech House, pp.271-279, 1991.
- [5] B.Edde, *RADAR Principles, Technology, Applications*, Prentice Hall, pp.147-161, 1993.
- [6] M. Skolnik, *RADAR Handbook*, 2nd edition, McGraw-Hill, pp.2.46-2.47, 1990.
- [7] D. C. Schleher, *Introduction to Electronic Warfare*, Artech House, pp.367-368, 1986.
- [8] R. G. Wiley, *ELINT : The Interception and Analysis of Radar Signals*, Artech House, pp.197-209, 2006.
- [9] H. K. Mardia, "New techniques for the deinterleaving of repetitive sequences," *IEE Proceedings*, Vol.136, Pt. F, No.4, pp.149-154, August 1989.
- [10] K. Nishiguchi, M. Kobayashi, "Improved algorithm for estimating pulse repetition intervals," *IEEE Trans. on Aerospace and Electronic Systems*, Vol.36, No.2, pp.407-421, April 2000.
- [11] W. L. Stutzman, G. A. Thiele, *Antenna Theory and Design*, John Wiley & Sons, pp.419-433, 1981.