

# Analysis and Estimation of Vertical Beam Characteristic Parameters for Phased Array Radar

Long Xiang, Jian-Jiang Ding, Xiao-Wei Shi and Zhi-Fang Zuo

**Abstract** Vertical Coverage Pattern (VCP) is an important index in radar engineering design, which determines the performance and parameters of the radar. Based on the VCP of phased array radar, the variation and characteristic parameters of a vertical beam are analyzed deeply. In this paper work, we discuss a prediction method and propose estimation formulas for the characteristic parameters. We estimate the unknown parameters of a specific radar and its VCP by comparative analysis of two typical radars as a case study. The results of this analysis provide a novel method for new radar jamming technology, offering better theoretical significance and reference value in the practice of engineering.

**Keywords** Phased array radar · VCP · Parameter estimation · Vertical beam

## 1 Introduction

Phased array radar (PAR) has the merit of beam agility, waveform agility, and flexible operation patterns. As such, it is difficult to locate and jam PAR effectively. PAR has always been a research focus and difficult problem in the field of radar ECM (Electronic Counter Measure) [1–5]. Here, we quantitatively analyzed the vertical beam parameters based on the VCP of PAR. The estimation and prediction to the detection capability of radar has also been made by VCP simulation.

---

L. Xiang (✉) · J.-J. Ding · Z.-F. Zuo  
Air Force Early Warning Academy, Wuhan, Hubei, China  
e-mail: dick\_500@163.com

J.-J. Ding  
e-mail: djj1965@163.com

Z.-F. Zuo  
e-mail: zzf1982@163.com

X.-W. Shi  
The 29th Research Institute of CETC, Chengdu, Sichuan, China  
e-mail: sxw1979@163.com

## 2 Beam Characteristic of BES-PAR

BES (Beam Elevation Scanning)-PAR denotes specifically the 3D air surveillance phased array radars with electronic scan in elevation (vertical) and mechanical rotation in azimuth (horizontal). The width and shape of the azimuth beam is usually fixed. The width and shape are determined by the technical index of BES-PAR. However, the vertical beam is raster scanning and can form multiple beams within VCP [6].

The multiple beams in vertical plane have some remarkable characteristics, and their values mainly depend on the selection of the operation mode and working parameters of PAR, which also embody the flexibility of PAR operation. The characteristics of BES-PAR can be described with the following formula:

$$C_{eb,i} = \{\beta_{e,i}, \theta_{e,i}, n_{t,i}\tau_{t,i}, f_{0,i}, t_{r,i}, p_{t,i}\} (i = 1, 2, \dots, N_e) \quad (1)$$

Here,  $N_e, \beta_{e,i}, \theta_{e,i}, n_{t,i}\tau_{t,i}, f_{0,i}, t_{r,i}, p_{t,i}$  denotes the number of beams in vertical plane, beam direction angle, beam width, number of transmitted pulses in each beam, carried frequency, PRF (Pulse Repetition Frequency) and pulse power, respectively.

## 3 Analyses and Estimation to the Characteristic Parameter of BES-PAR

Since the vertical beams of BES-PAR are varied, radar ECM cannot obtain accurate and overall information about radar. However, there is another way to analyze and estimate these parameters of the BES-PAR. The general law can be explored and predicted in this paper.

### 3.1 Full-Range Elevation Sector Width

For BES-PAR, under the Full-range Elevation Sector (FES), the transmitting beam can reach or exceed the radar maximum detection range. The approximate calculation formula for FES width is [7]:

$$\theta_1 = \arcsin\left(\frac{H_{\max}}{R_{\max}} - \frac{R_{\max}}{2k_a}\right) \quad (2)$$

Here,  $K_a$  denotes the effective radius of the Earth (approximately, 8500 km),  $H_{\max}$  denotes the maximum height, and  $R_{\max}$  denotes the maximum range.

### 3.2 Beam Width and Beam Direction Angle of FESB

The beams in FES are called Full-range Elevation Sector Beam (FESB); we need to calculate the beam width and direction angle of FESB. Firstly, the definition of the first full-range elevation sector beam (FFESB) is as follows: the beam which has the lowest beam pointing angle in the FES. The beam width of FESB is calculated by the following formula:

$$\theta_{e1} = \frac{\theta_1}{n_1 \cdot \Delta_e} \quad (3)$$

In formula (3),  $n_1$  denotes the number of beams which are used to cover the FES of  $[0, \theta_1]$ , the value of  $n_1$  is also required to provide the desired resolution, or aperture height.  $\Delta_e$  denotes the beam spacing between those elevation beams. Thus, the beam pointing angle of the other FESBs can be calculated by this formula:

$$\beta_{ei} = \beta_{e1} + (i - 1) \cdot \Delta_e \cdot \theta_{e1} \quad (4)$$

In formula (4),  $\beta_{ei}$  denotes the pointing angle of the  $i$ th FESB;  $\beta_{e1}$  denotes the pointing angle of FFESB; other parameters are same as formula (3).

### 3.3 Beam Width and Beam Direction Angle of UES

Above the FES, the region is called Upper Elevation Sector (UES). The scope of UES is from  $\theta_1$  to the max elevation angle ( $\theta_{\max}$ ). Therefore, the whole width of UES is:

$$\theta_{e2} = \theta_{\max} - \theta_1 \quad (5)$$

If we assume the number of the beam covering the whole UES to be  $n_2$ , which is also called Upper Elevation Sector Beam (UESB), each UESB's width can be calculate by an iteration method [8]. The iterative formula is given as:

$$\frac{\theta_{ehj}}{\theta_{e1}} = \frac{\sin(\beta_{ehj})}{\sin \theta_1}, \quad (j = 1, \dots, n_2) \quad (6)$$

$$\beta_{ehj} = \beta_{en1} + \Delta_e \cdot \sum_{k=1}^j \theta_{ehk} \quad (7)$$

In formula (6),  $\theta_{ehj}$  is the beam width of  $j$ th UESB; in formula (7),  $\beta_{en_1}$  denotes the pointing angle of  $n_1$ th FESB, which can be deduced from formula (4). Thus, each UESB's pointing angle can be calculated in the following formula:

$$\beta_{ej} = \beta_{en_1} + j \cdot \Delta_e \quad (j = 1, \dots, n_2) \quad (8)$$

### 3.4 Constraint Relationship Between ESST and ADT

**Elevation Sector Scanning Time (ESST).** For radar's FESB, the time needed to scan the whole elevation sector is called Elevation Sector Scanning Time (ESST), noted by  $t_{es}$ . Based on the above analysis, the calculation formula of  $t_{es}$  is:

$$t_{es} = \sum_{i=1}^{n_1+n_2} (\tau_{t,i} + t_{r,i}) n_{t,i} \quad (9)$$

The definitions of parameters in formula (9) are given in formula (1).

**Azimuth Dwell Time (ADT).** The definition of Azimuth Dwell Time (ADT) is given as:

$$t_a = \frac{t_s \cdot \Delta_a \cdot \theta_a}{A_m} \quad (10)$$

In formula (10),  $A_m$  denotes the azimuth sector width;  $t_s$  denotes the radar antenna scanning period;  $\theta_a$  denotes the azimuth beam width;  $\Delta_a$  denotes the spacing between adjacent azimuth beams. The relationship formula of them is given by:

$$t_{es} < t_a \quad (11)$$

## 4 A Case Study to Typical BES-PAR

In this case study we will examine TPS-59 radar (TPS-59), designed by Lockheed-Martin Company, as a case of BES-PAR. TPS-59's specification parameters and VCP can be found in Ref. [9]. Its derivative product is TPS-117 radar (TPS-117). The unknown specification parameters and VCP of TPS-117 can be estimated, by means of comparative analysis of the two radars' specifications and using the discussed in this paper.

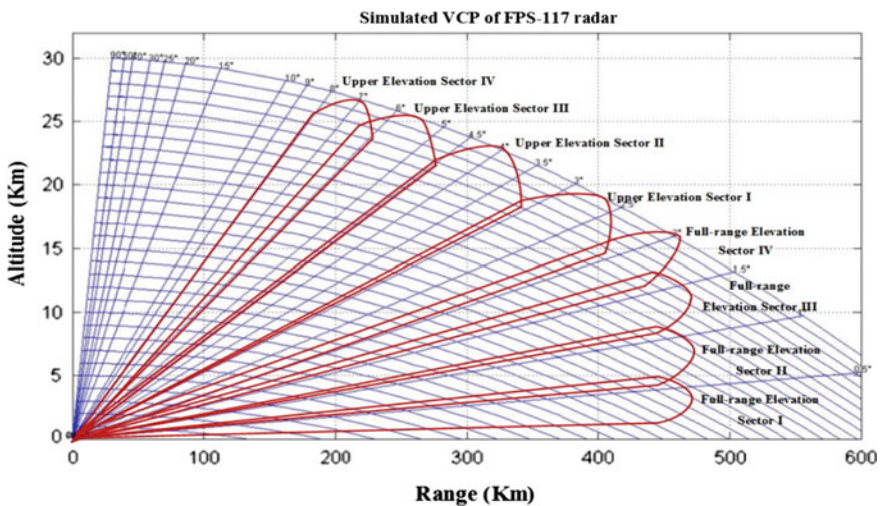
### 4.1 Arrangement of Beam Positions and Pulse Number in FES & UES

TPS-59 arranges three FESBs in its FES ( $\theta_1 = 1.7^\circ$ ), and arranges another five UESBs in the UES. According to the formulas (3–8), it can be concluded that TPS-117 will arrange four FESBs in FES ( $\theta_1 = 2.2^\circ$ ). The relative parameters can be obtained by MATLAB’s numerical calculation [10], as shown in Table 1.

TPS-59 transmits 11 short-range beams in the short-range elevation sector and places a three-pulse sequence with PRF of 625 Hz in the three low elevation sectors for MTI processing. The estimated number of beams is about 9–10, enough to cover the short-range elevation sector for TPS-117. It’s also assumed that TPS-117 is similar to TPS-59 for MTI with PRF of 1100 Hz. So the number of short-range

**Table 1** Beam position of TPS-117 in VCP

Secor name	Beam point angle (°)	Half-power down point (°)	Half-power up point (°)
Full-range elevation sector I	0.344	0	0.688
Full-range elevation sector II	0.983	0.55	1.237
Full-range elevation sector III	1.444	1.1	1.788
Full-range elevation sector IV	1.993	1.65	2.337
Upper elevation sector I	2.793	2.293	3.293
Upper elevation sector II	3.914	3.214	4.614
Upper elevation sector III	5.482	4.502	6.462
Upper elevation sector IV	7.072	6.078	8.066



**Fig. 1** VCP of TPS-117 (in FES)

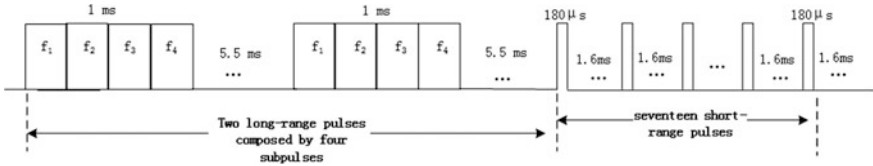


Fig. 2 Transmitting pulses train of TPS-59

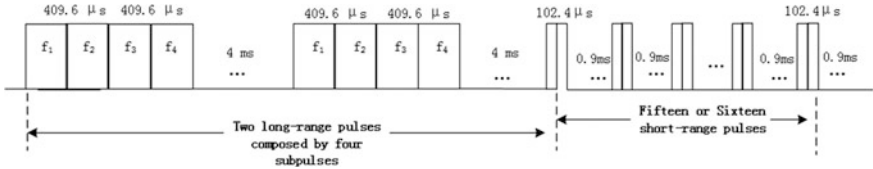


Fig. 3 Transmitting pulses train of TPS-117

pulses for TPS-117 is about 15–16. Based on the results of the calculations above, we get the VCP of TPS-117, as shown in Fig. 1.

### 4.2 Calculation of ESST and ADT

The transmitting pulses train of TPS-59 is shown in Fig. 2, the transmitting pulses train of TPS-117 is shown in Fig. 3, the ESST of TPS-117 can be calculated as  $t_{es-117} = 24.67-25.67$  ms, and the ADT is  $t_{a-117} = 61.1$  ms, it also has  $t_{es-117} < t_{a-117}$ .

## 5 Conclusion

In this paper, the vertical beam characteristics and parameters of BES-PAR have been analyzed and researched. The exploratory idea of digging the performance parameters and operation mode of an unknown radar, provides a new method for the research and development of ‘adaptive, precise, intelligent’ jamming technology.

## References

1. Chen, C.X., He, M.H., Li, H.F.: An improved radar emitter recognition method based on D-S theory. *Chin. J. Electron.* **24**(3), 611–615 (2015)
2. Petrov, N., Jordanov, I., Roe, J.: Radar emitter signals recognition and classification with feed forward networks. *Comput. Sci.* **22**(5), 1192–1200 (2014)
3. Liang, H.D., Han, J.H.: Clustering and sorting radar signals based on multi-wavelet packets characteristics of bispectrum. *Acta Photonica Sinica* **43**(3), 1–7 (2014)
4. Focke, R.W., de Villiers, J.P., Inggs, M.R.: Interval algebra—an effective means of scheduling surveillance radar networks. *Inf. Fusion* **23**(2), 81–98 (2015)
5. Yang, D.: Technology researches on airborne fire control radar emitter identification. Ph.D. thesis, Nanjing University of Aeronautics and Astronautics, Nanjing, China (2014)
6. David, K.B.: Radar System Analysis and Modeling. Artech House, London (2005)
7. Wang, X.M., Kuang, Y.S., Chen, Z.X.: Surveillance Radar Technology. Publishing House of Electronics Industry, Beijing (2008)
8. Stewart, G.T., Zheng, Y.L., Wong, W.K.: Machine learning for activity recognition: hip versus wrist data. *Physiol. Meas.* **35**(11), 2183–2189 (2014)
9. Ground-Based Air Surveillance Radars. <http://www.lockheedmartin.com/us/products/ground-based-air-surveillance.html>
10. Bassem, R.M.: MATLAB Simulations for Radar Systems Design. Chapman & Hall/CRC Press, New York (2006)