Chapter 40
A New EIRP Measurement for User Equipments Based on CRDSS

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Abstract The radiated signal of user equipment enters into the station effectively only with the proper power, so effective isotropic radiated power (EIRP) is the main factor for design of user equipment. The precise value of EIRP is measured in the two dimensional plane condition of darkroom. While in outside circumstance, ERIP is calculated complicatedly by many parameters of communication route, but the final result is not right. In this paper, to satisfy the operation need of Comprehensive Radio Navigation Satellite Service (CRDSS), emission route is abstracted into mathematical models, apart from the circumstance, distance and device factor, the angle formed by antenna and satellite is taken and the right valve of EIRP of multiple satellites is got simultaneously by the geometry relation of solid space. EIRP measurement is executed on the GEO and IGSO satellite by this way, it is useful for evaluation of effective entrance range to the station and design of satellite constellation. On the basis, the concept of extended angle is proposed to testify the practicableness of satellite. Experiment data in the east and west polar region of china proves out this measurement way. The conclusion is that ERIP of 4dBw is proper lower limit for signal to enter into the station in the condition of satellite constellation and signal processing.

Keywords CRDSS · EIRP · Effective extended angle · Link calculation

40.1 Introduction

CRDSS [1] is the special operation of Compass navigation system. The function of position service share was performed only by the technique of GPS position and communication in the past time, but it is totally substituted by CRDSS. CRDSS

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J. Sun et al. (eds.), *China Satellite Navigation Conference (CSNC) 2013 Proceedings*, Lecture Notes in Electrical Engineering 243,
DOI: 10.1007/978-3-642-37398-5_40,

combines measurement, orientation and position report, simplifies the different demand of user and complex math processing into the unified manipulation. Complexity of user equipment and the basic facilities is reduced by CRDSS. The technique is not the simple mixture of navigation and communication, but a entirely new mode and service idea to meet the diversified needs of the application.

CRDSS is a radio positioning system of measuring distance among multiple reference stations, which includes the parts of RDSS of two satellites, RDSS of three satellites and Radio Navigation Satellite System (RNSS). The most distinctive difference with RNSS is that user equipment need transmit a response signal to different type of satellites (2 GEO satellites and 1 IGSO satellite). It is urgent to measure EIRP of user equipment accurately and quickly by practical way to ensure that transmitting signal is received and relaid through satellite transponder. The classical calculation method based on communication link involves many application parameters and link processing, so this way is not practical in the project realization due to parameter accuracy and computational complexity.

In view of the above problems, this paper analyses the systematical transmission link of CRDSS device, and sets up a model way of EIRP measurement and quantitative expression making direct use of signal factors and orbital elements apart from the circumstance, distance and device factor. The concept of effective extended angle is proposed to reflect satellite availability, and field test data proves the effectiveness of the method. The research method and conclusion provides basis for design of user equipment. It is the reference to the design of constellation of navigation system.

40.2 Analysis of Transmission Link

40.2.1 Explain of Process

Link Composition of CRDSS is shown in Fig. 40.1. Measurement and control center (MCC) in the ground transmits signal of measuring distance. After receiving the forward signal through any satellite, user equipment transmits response signal to three satellites. MCC receives the response signal through three satellites, gets the

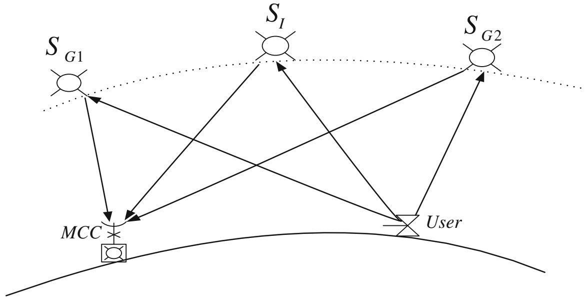


Fig. 40.1 Composition structure of CRDSS system

round trip distance from MCC to user, and completes the solution of user position finally. From the above processing, three satellites compose the certain geometric relationships and relay the signal from the user equipment to get good position results. It is very important to set proper value of EIRP.

40.2.2 Calculation in Theory and Limitation

It is an usual computing method [2] that EIRP is deducted according to received electrical level and state of link from the ground to satellite. Input link of CRDSS is random access for multiple user signals. Due to power difference of user, the cross-correlation value produced by large power and small power is so much larger than the autocorrelation value that the signal of small power does not enter into the station [3, 4]. So it is very important to set the proper EIRP and the acceptable lower level respectively for user and MCC. In addition, these factors such as G/T of satellite, signal gain of satellite channel, loss of free space, and loss of weather produce the influence of ERIP calculation. The measure method of G/T of satellite can be found in the paper [5].

Table 40.1 shows the calculation value of electronic level and ERIP while the user equipments of 5 and 10 W power amplifier work in Beijing region. From the test, the EIRP value of 10 W power is 2 times as much as that of 5 W power, which is matching to the true ratio. The problem is that EIRP value is 2 or 3 dB larger than the true power. There are two reasons to explain why it happens. One is that many indefinite factors cause the complex test in the outdoor environment. ERIP calculation involves many parameters, which are defined by the typical and statistical value as described in the parameter Table 40.2, but these values are not ac-curate number in the certain environment only to express theoretical significances. The other is the error caused by difference of processing equipment in the station and volatility of level in calculation of electronic level.

Table 40.1 Electronic level of entering into the station and EIRP value

Power amplifier (W)	Designed angle	Inbound electrical level			Calculation value of EIRP		
		Beam 1	Beam 3	Beam 5	East	West	Middle
10	180/90	53.9	51.8	51.7	15.9	13.8	13.8
	180/80	53.9	51.7	51.7	15.9	13.7	13.8
	180/70	53	49.3	53.4	15	11.3	15.5
	180/50	52.5	49.3	53.5	14.5	11.3	15.6
	180/30	53.65	49.9	52.5	15.6	11.8	14.6
5	180/90	0	46.85	47.3	0	8.8	9.3
	180/80	49	48.39	50	11	10.5	12
	180/70	50.34	49.4	50	12.3	11.5	12
	180/50	50.7	48.3	50.6	12.7	8.8	12.5
	180/30	43.57	47.5	49	0	9.5	11

Table 40.2 Working parameters of link calculation

Parameter of uplink	Parameter of downlink
User EIRP	Receiving power
Free Space loss of uplink	Free space loss of downlink
Loss of weather (T1)	Loss of weather (T2)
G/T1 of satellite	G/T2 of central station
Carrier noise ratio of uplink	Carrier noise ratio of downlink

40.3 Modeling of Included Angle Factor and Actual Calculation

Based on the definition of EIRP, the value of EIRP is measured and calculated by the model of included angle. On the basis, the actual prediction is executed. The definition [6] is as follows:

$$EIRP = P_T(f)G_T(f) \tag{40.1}$$

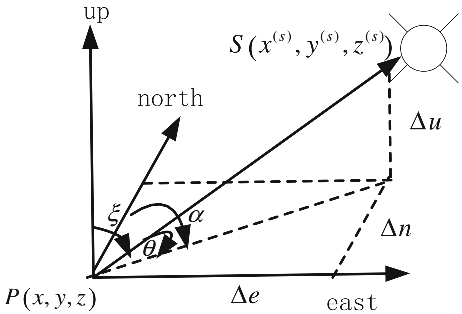
where P_T is power density of transmission signal, G_T is power gain, which is directly related with included angle between the antenna and the satellite (Fig. 40.2).

40.3.1 Calculation of Satellite Angle [7]

From the above figure, the coordinate of user position in Earth centered Earth fixed frame system is (x,y,z), the coordinate of satellite position is (x^s,y^s,z^s), the observation vector from user to satellite is

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \begin{bmatrix} x^s \\ y^s \\ z^s \end{bmatrix} - \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{40.2}$$

Fig. 40.2 Diagram of satellite angle



The observation vector $[\Delta x \quad \Delta y \quad \Delta z]^T$ is substituted for vector in the local level frame system as point p is base point, the alteration relationship is

$$\begin{bmatrix} \Delta e \\ \Delta n \\ \Delta u \end{bmatrix} = S \bullet \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} \tag{40.3}$$

In the expression, $S = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\varphi \end{bmatrix}$ (ϕ is latitude in location, λ is longitude in location).

Based on the principle of trigonometry as described in the figure, the expression of elevation and azimuth angle of the satellite is as follows:

$$\theta = \arcsin\left(\frac{\Delta u}{\sqrt{(\Delta e)^2 + (\Delta n)^2 + (\Delta u)^2}}\right) \tag{40.4}$$

$$\alpha = \arctan\left(\frac{\Delta e}{\Delta n}\right) \tag{40.5}$$

40.3.2 Elevation Angle of GEO Satellite

As an example of the middle latitude region of 40°, the range of longitude is from 70 to 140°, which covers the entire region of china from the east to the west. The variety of elevation angle of east, west and middle satellite by above calculation is shown in the Fig. 40.3. From the figure, the elevation angle of middle spare satellite is more than 30° in the whole region. The elevation angle of east satellite

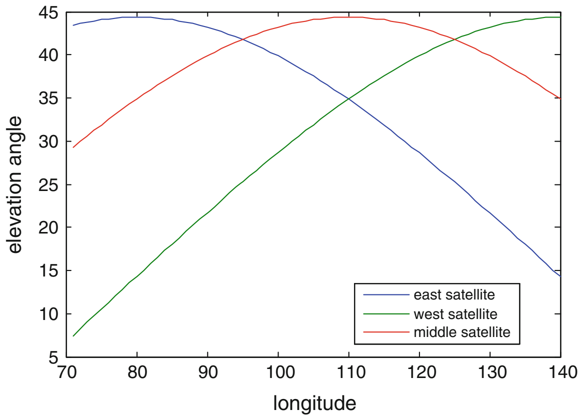


Fig. 40.3 Changes of GEO satellite elevation angle

is pairing with that of west satellite. In the any region, there are two available satellites of high elevation angle for users. The results show three GEO satellites can complete the RDSS operation of double satellites in the whole region of china and surrounding areas.

40.3.3 Elevation Angle of IGSO Satellite

To be the certain geometric shape, CRDSS system usually involves one IGSO satellite. The intersection formed by the earth surface and connection between satellite and earth center is called point under satellite. The point shape of IGSO is "8" through crossover point of the equator. The moving cycle is 24 h. Variety of IGSO elevation angle in the region of high latitude, middle latitude, and low latitude is shown with the passage of time. The lower is latitude, the longer is the effective duration time of elevation angle. The effective duration time of elevation angle is more than 12 h in the region of high latitude (60°). Two alternate IGSO satellites provide effective CRDSS service for users in the above place (Fig. 40.4).

40.3.4 Calculation of Included Angle

Provided that the angles of satellites and users are known, the included angle between user and satellite can be estimated. In the Fig. 40.5, point A expresses antenna of receivers, P0 expresses horizontal plane that the receiver is located in. P1 expresses vertical plane that satellite is located in. Point B expresses the point that Plane P1 intersects with connecting line between satellite and receiver. Point

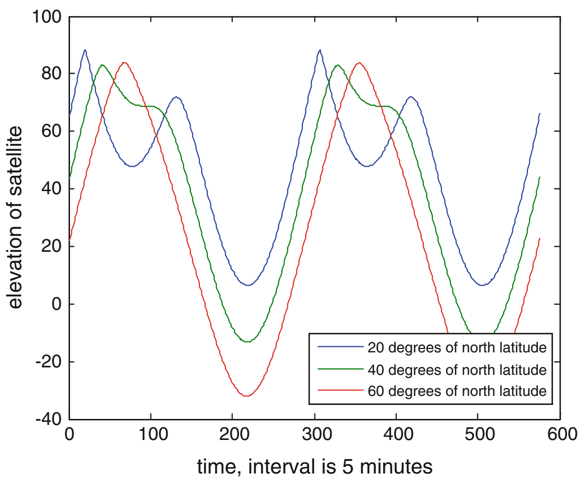


Fig. 40.4 Changes of IGSO satellite elevation angle

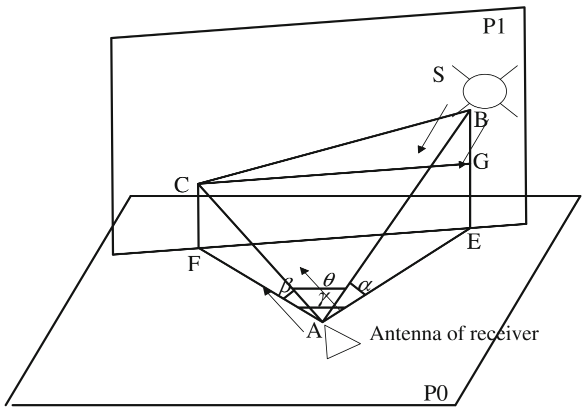


Fig. 40.5 Diagram of included angle calculation

C expresses point that antenna normal intersects with plane P1. E expresses the vertical point of B in the plane P0. F expresses the vertical point of C in the plane P0. G expresses vertical point of C in the line BE. α expresses elevation angle of satellite, β expresses elevation angle of antenna. γ expresses horizontal azimuth angle of satellite and antenna. θ expresses included angle of satellite and antenna, which is the last destination. To ensure the uniqueness of plane P1, P1 is perpendicular to P0. Projection length of Line AC in the plane P0 with the direction of antenna normal line is the same as that of line AB with the direction of satellite and user. This design simplifies subsequent calculation.

$$AB = \frac{AE}{\cos(\alpha)} \tag{40.6}$$

$$AC = \frac{AF}{\cos(\beta)} \tag{40.7}$$

Based on Eqs. (40.6) and (40.7), according to Cosine theorem,

$$EF = \sqrt{AE^2 + AF^2 - 2 \cdot AE \cdot AF \cdot \cos(\gamma)} \tag{40.8}$$

$$CG = EF \tag{40.9}$$

$$BC = \sqrt{BG^2 + EF^2} \tag{40.10}$$

If the length of line the AB, AC, and BC is known, according to cosine theorem, the angle value of θ is found.

The analysis Fig. (40.6a–d) are shown in the different region based on the above theory. Provided that the azimuth angle is stationary and the elevation angle of satellite is small, the larger is the elevation angle of antenna, the smaller is angle between antenna and satellite. Conversely, when the elevation angle is large, the variety of antenna elevation angle has small effect on the above angle. Or the larger is elevation angle, the larger is the above included angle.

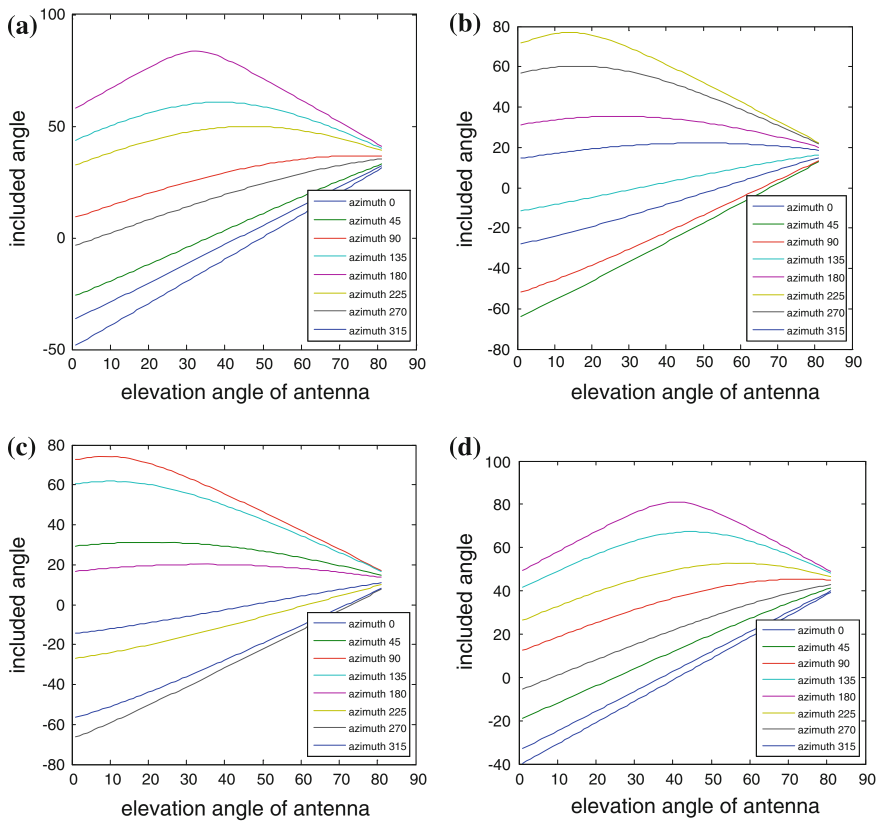


Fig. 40.6 **a** Analysis of east sat. in Fy. region. **b** Analysis of west sat. in Fy region. **c** Analysis of east sat. in KS. region. **d** Analysis of west sat. in KS. region

When the elevation angle of antenna is stationary, the angle range from 30 to 60° is suitable according to using habit. Corresponding to the included angle (more than 30°), the range of azimuth angle is called “effective extended angle”. Effective extended angle is 135 and 90° respectively corresponding to east and west satellite in fuyuan region. Effective extended angle is 90 and 180° respectively corresponding to east and west satellite in kashi region. The large range of effective extended angle shows that the receivers produce good results of entering into the station in the region.

40.4 Verification of Actual Measurement Data

40.4.1 Performance Detection of Transmission Antenna

To get high power gain of transmission, entire directional antenna is used in the receiver. Out of roundness of antenna is 1 as far as possible. Variety of power gain in the different elevation angle is small. Restricted with the technical and productive factor, circularly polarized microstrip antenna in use produces the certain deviation. Experiment results show that from the directional diagram of antenna in the dark-room the range of power gain is within 3 dB in the elevation range from 30 to 90°.

40.4.2 Analysis of Actual Data

To verify the practical results of receiver ERIP in the outside environment, the representative test regions such as kashi in xinjiang province and fuyuan province in Heilongjiang are selected in this paper. These two places are located in the west and east bottom of china to test service performance of GEO satellite in the edge of position.

Experiment is done in the open region without the obvious interference. Horizontal calibration instrument is used to define base level. Receiver is placed on the horizontal framework, continuous position is applied after setting certain azimuth and pitch. After the test is finished, the dependent level data of entering into the station is extracted from the center control system, data valve of included angel is got in the principle described in the second part of paper. These above kinds of data are filled in the Tables 40.3 and 40.4.

Due to difference of the region that satellite wave beams of entering into the station cover, beam 1, 3, and 5 are main waves in fuyuan, beam 2, 4, and 6 are main waves in kashi. From the table, included angle in theory is larger, the electrical level valve of entering into the station is larger. This phenomenon proves exactness of theoretical calculation. When the included angle is more than 25°, the corresponding electrical level is effective, the corresponding azimuth of receiver is called effective azimuth. Effective azimuth range of east satellite in fuyuan is from 90 to 270°. Effective azimuth range of West Satellite in fuyuan is from 180 to 270°, the above value of Ready Satellite is in the middle of two above ranges. Effective azimuth range of west satellite in kashi is from 45 to 270°. Effective azimuth range of east satellite in kashi is from 45 to 135°, the above value of Ready satellite is so. This result is similar to the theoretical calculation value in the Sect. 3.4.

Comparing the level data of kashi with that of fuyuan, the level of entering into station is also similar when the included angle is identical. In the same place, the level of different satellites is similar when the included angle is similar. The important inference is that included angle is main factor of determining ERIP irrelevant to the certain user position and satellite.

Table 40.3 Test resulting data in Fuyuan region

Azimuth/elevation		Included angle calculation			Inbound Electrical level in Fuyuan		
		Beam 1	Beam 3	Beam 5	Beam 1	Beam 3	Beam 5
0	30	−25.37	−15.86	−23.29	0	0	0
0	60	4.43	−0.815	3.33	24.98	29.5	35.5
45	30	−8.83	−42.77	−28.82	0	0	0
45	60	13.66	−14.388	0.462	27.9	38.8	32.4
90	30	22.09	−37.89	−8.11	38.5	33.49	32.63
90	60	32.81	−12.18	11.83	46.31	31.82	41.71
135	30	58.23	−6.70	25.33	49.2	0	42.33
135	60	54.65	4.37	32.24	48.74	19.63	46.7
180	30	82.29	31.47	63.06	42.74	47.24	45.84
180	60	63.75	26.42	53.24	46.7	46.87	45.89
225	30	45.73	68.09	78.00	46.05	49.31	46.6
225	60	47.5	42.78	58.33	46.93	49.85	47.2
270	30	10.74	59.64	39.58	0	49.87	47.12
270	60	25.62	39.92	40.86	46.26	49	44.85
315	30	−16.71	21.43	3.90	0	0	0
315	60	9.13	20.77	19.01	33.6	0	37.4

Table 40.4 Test resulting data in Kashi region

Azimuth/elevation		Included angle calculation			Inbound electrical level in Kashi		
		Beam 1	Beam 3	Beam 5	Beam 1	Beam 3	Beam 5
0	30	−8.83	−15.61	−13.42	0	38.67	32.17
0	60	1.39	14.29	10.14	8.24	50.18	36.03
45	30	29.59	−2.315	16.88	48.93	49.12	44.4
45	60	23.45	22.27	28.55	47.1	48.26	45.24
90	30	65.38	24.59	53.16	47.64	51.52	46.38
90	60	39.63	39.98	50.56	50.25	50.95	49.48
135	30	58.12	56.39	87.10	46.2	51.37	47.88
135	60	37.10	62.02	62.48	50.37	51.82	48.98
180	30	20.43	74.99	50.31	12.41	50.26	47.22
180	60	18.33	73.73	48.98	35.21	48.98	45.71
225	30	−17.35	47.49	14.29	40.3	50.94	41.92
225	60	−3.39	55.88	26.92	5.56	49.34	45.3
270	30	−45.52	16.30	−15.25	0	45.70	0
270	60	−17.40	34.36	9.11	0	47.8	15.9
315	30	−40.81	−7.82	−27.48	0	38.39	21.46
315	60	−15.33	18.89	2.51	0	50.53	44.49

40.5 Conclusions

Not using the complicated way of link analysis, a practical calculation model of ERIP is set up in the outer three Dimensional spaces. According to the position angle of receiver, the included angle between antenna and satellite is calculated through the geometry model. Combined with power amplifier and electrical level value of entering into station, the basic conclusion is that when the power is 5 W and the angle between receiver antenna and satellite is more 30°, corresponding ERIP of 4dBw can ensure that transmission signal enters into station effectively. The concept of effective extended angle is proposed. The test in the east and west bottom of china shows the effective extended angle of satellite with high elevation angle is more than 180°, which of satellite with low elevation angle is more than 90°. The value of extended angle shows the availability of satellite. Based on the running orbit of satellite, 3 GEO satellites and 2 IGSO satellites can satisfy the needs of CRDSS service in china and nearby region.

Acknowledgments This work is supported by Zhong Sen communication science and technology corporation of ChengDu.

References

1. Tan S (2011) The comprehensive RDSS global position and report. National Defence Industry Press, China
2. Tan S (2010) The engineering of satellite navigation and positioning. National Defense Industry Press, China
3. Behrens RT, Scharf LL (1994) Signal processing applications of oblique projection operators. IEEE Trans Sig Proc 42(6):P1413–P1423
4. Morton YT, Tsui J, Lin D (2003) Assessment and handling of CA code self-interference during weak GPS signal acquisition. ION GPS-03 2003, Portland, pp P646–P653
5. Wen R, Pan Y (2005) On-orbit calibration of G/T value of effective load on the synchronous satellite. Radio Eng 35(1):P33–34
6. Mirshafiei M, Abtahi M, LaRochelle S (2008) Wideband antenna EIRP measurements for various UWB waveforms. In: Proceedings of the 2008 IEEE international conference on ultra-wideband, vol 1, pp P125–128
7. Xie G (2009) Principles of GPS and receiver design. Electronics Industry Press, China