



Over the Air Test Method for Beidou Intelligent Terminals

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Abstract. The number of Beidou intelligent terminal is dramatically increasing recently. Only during 2017, there have been More than 200 mobile communication terminals supporting BDS applied for telecom equipment access to network license. It's important to evaluate the Beidou antenna performance of these intelligent terminals but currently there is neither specification nor common methods. Over-The-Air (OTA) test evaluates three-dimension (3D) radiated antenna performance in anechoic chamber to approach the real user experience. In this paper, an over the air test method for Beidou intelligent terminal is proposed, including standalone mode and communication assisted mode. The test scenarios and test procedures for radiated 3D Carrier-to-Noise (C/N₀) pattern measurement and radiated sensitivity measurement are described. An over the air test system is developed in China Telecommunication Technology Lab (CTTL) and a number of intelligent terminals supporting Beidou are tested. The results indicate that although large numbers of terminals are claimed supporting Beidou, its Beidou antenna performance is relatively poor and when Global Position System (GPS) is not available, Beidou positioning cannot meet the user requirements currently. Thus, it is urgent to standardize the Beidou OTA technical requirements and test methods of intelligent terminals.

Keywords: Beidou navigation satellite system (BDS) · Assisted-Beidou navigation satellite system (A-BDS) · Intelligent terminal · Over the air test (OTA test)

1 Introduction

The OTA test can evaluate 3D radiated antenna performance of terminals with full anechoic chamber which can simulate the effects of the operators by testing the antenna performance under different statuses such as free space, hand and head phantom. So, OTA test is crucial for evaluating navigation and positioning terminals' performance since it indicates the real user experience.

Recently, the number of Beidou intelligent terminal is dramatically increasing. Only during 2017, there have been More than 200 mobile communication terminals supporting BDS applied for telecom equipment access to network license. It's important to test their Beidou antenna performance. CTIA OTA test plan [1] version

3.7 defines the GPS and GLONASS standalone OTA test method; A-GPS and A-GLONASS OTA test method has already been defined in version prior, which is evaluated by Total Isotropic Sensitivity (TIS), Upper Hemisphere Isotropic Sensitivity (UHS) and Partial Isotropic GNSS Sensitivity (PIGS) to measure the 3D radiated receiving sensitivity performance. While as for Beidou OTA test method, it hasn't been defined in CTIA specification. 3GPP technical specification 37.571.1 [2] defines A-GNSS radio frequency (RF) conducted test methods including AGPS, A-BDS and A-GLONASS; however, the test cases only evaluate conducted RF performance not including antenna performance. Meanwhile, Ref. [3] only includes network assisted mode doesn't consider standalone mode. In the 17 standards issued by China satellite navigation system office, standard [3] mainly focuses on GNSS antenna performance test, but it only includes Voltage Standing Wave Ratio (VSWR), noise coefficient, gain and other parameters of circular polarization antenna itself, not involves the antenna sensitivity of the entire Beidou equipment. In [4], the RF conducted performance test methods and test system of the Beidou terminals are introduced, including standalone mode and the network assisted mode. (The mainly difference between standalone BDS and A-BDS is that, assistant data including time, ephemeris, almanac and approximate position can be supplied by network for A-BDS mode. The BDS intelligent terminals in the market now can only support standalone mode.)

In a word, currently there is neither Beidou OTA test specification nor common method for A-BDS mode and standalone BDS mode. Considering the current situation, a Beidou antenna OTA performance test method, including the standalone mode and network assisted mode, is proposed in this paper and a test system is developed according to the proposed method, based on which a large amount of Beidou intelligent terminals are tested.

2 System Architecture

The BDS antenna performance can be test in full anechoic chamber as shown in Figs. 1 and 2 for standalone mode and network assisted mode respectively. BDS standalone system mainly includes satellite signal simulator and communication antenna. For network assisted mode, there should be a mobile network simulator additionally. The satellite signal simulator is used to simulate the satellite navigation signal, satellite orbit, atmospheric delay error and user trajectory, while the mobile network simulator is used to simulate the base station signal and send the network assisted information.

For network assisted mode, the communication between the equipment under test (EUT) and system to collect measurement data, such as positioning results and C/N0 information, is via signaling protocol defined in corresponding cellular technologies, e.g. RRLP in GSM, RRC in WCDMA, LPP in LTE or IP connection in SUPL. For standalone mode, those signaling protocols in control plane and IP connection in user plane are not applicable, so the information needs to be transmitted by other way. In order to simply the design and implementation to support different types of EUTs, the communication protocol is defined to be running on TCP/IP transport layer in our system as currently discussed in CTIA version 3.7. The information loopback method is the principal matter to be solved for standalone mode. Two methods are used in

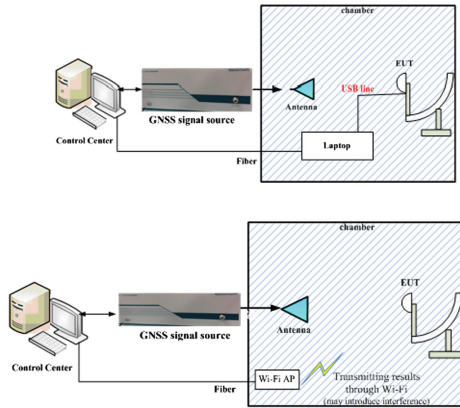


Fig. 1. Standalone BDS OTA test system

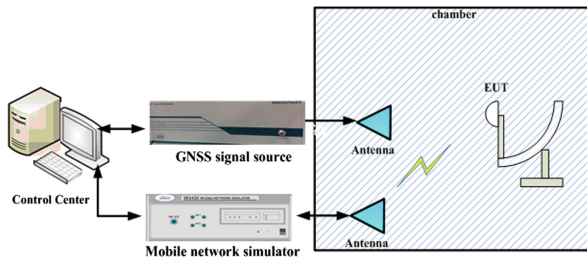


Fig. 2. A-BDS OTA test system

CTTL lab, one is USB-optical fiber, in which a laptop is placed in the chamber to collect information from the EUT and transmit it to the control center through fiber. The other is Wi-Fi, in which a Wi-Fi Access Point (AP) is placed in the chamber to loopback the information.

The TCP/IP protocol is request/response based. According to the test procedure, the system sends request to EUT and EUT acts based on the command and provides response to the system. The format of the request/response message is defined as follows:

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<Message ID><PARAM1 ID>:<PARAM1 VALUE>;
<PARAM2 ID>:<PARAM2 VALUE>;
<PARAMN ID>:<PARAMN VALUE><CR><LF>
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There are 6 messages needed to enable standalone GNSS performance test as being discussed in CTIA. They are REQ_RESET_GNSS, RESP_RESET_GNSS, REQ_CN_MEASUREMENT, RESP_CN_MEASUREMENT, REQ_LOCATION and RESP_LOCATION. The detailed definition and description of each message is in Table 1.

Table 1. Message definition and description.

Message ID	Description	Direction	Parameters & values
REQ_RESET_GNSS	Request UE to clear all GNSS data and all historical data and result	System to EUT	N/A
RESP_RESET_GNSS	Response whether the reset GNSS command succeed or not	Device to EUT	RESULT: <OK/FAIL>
REQ_CN_MEASUREMENT	Request UE to measure C/N for GNSS	System to EUT	GNSS: <GPS/GPS, GLONASS>; ACCURACY: <H/M/L>
RESP_CN_MEASUREMENT	Response to report C/N measurement	EUT to system	RESULT: <OK/FAIL>; TOTAL: <#>; GNSS: <GPS/GLONASS/BDS>; SAT_ID: <#>; CN: <#>
REQ_LOCATION	Request UE to report current location	System to EUT	ACCURACY: <H/M/L>
RESP_LOCATION	Response to report UE location	EUT to system	RESULT: <OK/FAIL>; LAT: <#>; LONG: <#>; ALT: <#>

3 Test Method

The Beidou antenna test will determine the Total Isotropic Sensitivity, the Upper Hemisphere Isotropic Sensitivity ($\theta = 0$ to 90°) and the Partial Isotropic GNSS Sensitivity ($\theta = 0$ to 120°) of the Beidou terminals. This test can be applied to UE-based and UE-assisted A-BDS and standalone BDS devices. The test conditions are the same as that specified in [5]. The test procedure consists of the following measurements:

- Radiated 3D C/N0 pattern measurement
- Radiated sensitivity measurement.

3.1 Radiated 3D C/N0 Pattern Measurement

Devices supporting UE-assisted A-BDS can perform this section; however, devices supporting UE-based A-BDS only may not be able to perform this section. If a device supports both methods, then the radiated 3D C/N0 pattern measurement may be limited to UE-assisted A-BDS. The 3D C/N0 pattern will then be used for determining the

radiated BDS performance for both UE-assisted and UE-based A-BDS. If a device only supports UE-based A-BDS then the C/N0 data shall be stored in the EUT's internal memory or to enable UE-assisted A-BDS or some other test mode to perform the radiated 3D C/N0 pattern measurement. For standalone BDS, C/N0 pattern can be loopback by means of USB-optical fiber or Wi-Fi as shown in Fig. 1.

The pattern data shall be determined by averaging C/N0 measurement of all visible Beidou satellites for each measurement at each point on the sphere. The Beidou satellite simulator shall provide the number of satellites specified herein and each satellite vehicle shall be at the same power. The C/N0 pattern data should be obtained in tracking mode and shall be linearized by the linearization method described in Sect. 3.2.2.

The Beidou satellite simulator shall implement Scenario #1 as defined in 3GPP TS 37.571-5 section 6.2.1.2.1 subclause 7, which shall be reset before the initial satellites become invisible. The scenario parameters shall be set as required in section 7.2 subtest 9 of 3GPP TS 37.571-1, as shown in Table 2, except that random errors for the UE locations and location alternating requirement shall not be implemented. Meanwhile for standalone mode EUT response time is longer, e.g. 120 s. C/N0 pattern test is performed on all supported channels. Moreover, in order to save battery power, a lower transmission power is used that is at least 10 dB lower than the maximum transmission power.

Table 2. C/N0 pattern test parameters.

Parameters	Settings
Number of satellites	6
HDOP range	1.4–2.1
Propagation conditions	AWGN
Time assistance (for A-BDS only)	±2 s
Signal power	−133 dBm

3.2 Radiated Sensitivity Measurement

3.2.1 EIS

The radiated A-BDS and standalone BDS sensitivity search shall be performed at the position/polarization where the peak C/N0 value was obtained in the upper hemisphere. The EUT's receiver sensitivity will be the minimum Beidou signal level that results in a passing result for the applicable A-BDS/standalone BDS sensitivity test specified herein. The maximum sensitivity search step size shall be no more than 0.5 dB when the satellite vehicle power level is near the sensitivity level. The BDS satellite simulator shall implement GNSS Scenario #1 as defined in 3GPP TS 37.571-5 [6] section 6.2.1.2.1 for 3GPP TS 37.571-1 [2] subclause 7, sub-test 9 as Table 3, except that random errors for the UE locations and alternating location requirement shall not be implemented. The scenario shall be reset before the initial satellites become invisible. Sensitivity test will be conducted in capture mode, which means the sensitivity is acquisition sensitivity.

Note that the satellite power levels for the sensitivity test are such that there will be one satellite, which transmits 9 dB higher than the other satellites. The reported sensitivity level will be based on the power of the weaker satellites. The 1 dB test tolerance or test parameter relaxation for the absolute BDS signal level in C.2.1 in 3GPP TS 37.571-1 shall not be used in reporting the sensitivity measurement results.

Table 3. C/N0 pattern test parameters.

Test parameter description	Test parameter settings
Number of satellites	6
HDOP range	1.4–2.1
Propagation conditions	AWGN
Time assistance for A-BDS mode	Coarse, ± 2 s
EUT response time	120.3 s for standalone BDS mode 20.3 s for A-BDS mode
Success rate	45 successful fixes with the necessary accuracy out of 50 attempts (90%) for standalone BDS mode 95 successful fixes with the necessary accuracy out of 100 attempts (95%) for A-BDS mode
Position accuracy	101.3 m

3.2.2 Linearization

The C/N0 pattern measurements shall be linearized as follows. The peak value in the C/N0 pattern shall be determined from the data collected in Sect. 3.1. Re-position the EUT to the location with the maximum C/N0 measurement of the upper hemisphere. Measurements shall be made at a maximum of 1 dB steps from the peak C/N0 value in Sect. 3.1 to at least 10 dB below. These C/N0 measurements along with the corresponding signal level shall be used to linearize the pattern data collected in Sect. 3.1 such that every pattern data corresponds to a signal level. The linearization can be accomplished through piecewise linear method as shown in Fig. 3. C/N0 data that falls within the utilized step size shall be linearly interpolated, while C/N0 data that falls outside of the data set shall be linearized to a line that is extended using the same slope as linearization at the edge of the data set. By linearization, the 3D isotropic sensitivity can be calculated by C/N0 pattern.

We take two examples to illustrate the piecewise linear procedure. It is assumed that the best sensitivity on the peak point of the C/N0 pattern on the upper hemisphere is -154 dBm with $C/N0 = 47$. The corresponding relationship between the satellite power and C/N0 is as shown in Table 4. Suppose that we need to calculate the sensitivity of a point (target point 1) with $C/N0 = 27$. From Table 4, the power corresponding to $C/N0 = 27$ is -147 dBm, while the power corresponding to $C/N0 = 47$ is -126 dBm, which is 21 dB higher than that of target point 1. So that the sensitivity difference between the two points should also be 21 dB. Then the sensitivity of target

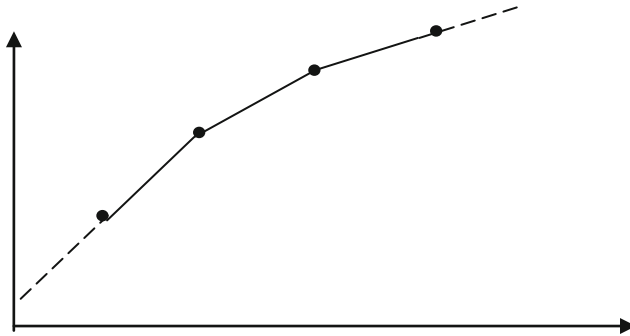


Fig. 3. Piecewise linear method

point 1 should be -133 dBm, 21 dB higher than -154 dBm. Suppose that we want to calculate the sensitivity of a point (target point 2) with C/N_0 42.5. From Table 1, the powers corresponding to 42 and 43 are -132 dBm and -131 dBm respectively. With piecewise linear the power corresponding to $C/N_0 = 42.5$ should be -131.5 dBm, while the power corresponding to $C/N_0 = 47$ is -126 dBm which is 5.5 dB higher than that of target point 2. Then the sensitivity of target point 2 should be -148.5 dBm, also 5.5 dB higher than -154 dBm.

Table 4. Relationship between satellite signal power and C/N_0 .

Power	-125	-126	-127	-128	-129	-130	-131	-132	-133	-134
C/N_0	48	47	46.5	45	45	44	43	42	41	40
Power	-135	-136	-137	-138	-139	-140	-141	-142	-143	-144
C/N_0	39	38	37	36	35	34	33	32	31	30
Power	-145	-146	-147	-148	-149	-150	-151	-152	-153	-154
C/N_0	29	27.8	27	26	25	23.5	23	22	20.5	19.5

3.2.3 Sensitivity Calculation

According to linearization in Sect. 3.2.2, isotropic sensitivity of every point on the sphere is obtained, from which the TIS, UHIS and PIGS of the EUT can be calculated by formula 1-3.

For a complete sphere measured with N theta intervals and M phi intervals, both with even angular spacing, the TIS is calculated as follows.

$$TIS \cong \frac{2NM}{\pi \sum_{i=2}^4 \sum_{j=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_i, \phi_j)} + \frac{1}{EIS_{\phi}(\theta_i, \phi_j)} \right]} \sin(\theta_i) \tag{1}$$

where EIS is the radiated effective isotropic sensitivity measured or calculated by linearization at each direction and polarization.

The UHIS, which represents the total power radiated in the theta range from 0 to 90°, is calculated as follows.

$$UHIS \cong \frac{2NM}{\pi \left(\sum_{i=1}^{\frac{N}{2}-1} cut_i + \frac{1}{2} cut_{\frac{N}{2}} \right)} \tag{2}$$

where $cut_i \cong \sum_{j=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_i, \phi_j)} + \frac{1}{EIS_{\phi}(\theta_i, \phi_j)} \right] \sin(\theta_i)$ represents the weighted sum of each conical cut.

For a complete sphere measured with N = 6 theta intervals (30° spacing) and M phi intervals, both with even angular spacing, the PIGS, which represents the total power radiated in the theta range from 0 to 120° is calculated as follows:

$$PIGS \cong \frac{2NM}{\pi \left(\sum_{i=1}^{\frac{N}{2}} cut_i + \frac{1}{2} cut_{\frac{N}{2}+1} \right)} \tag{3}$$

where: $cut_i \cong \sum_{j=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_i, \phi_j)} + \frac{1}{EIS_{\phi}(\theta_i, \phi_j)} \right] \sin(\theta_i)$ represents the weighted sum of each conical cut.

4 Results

We developed a Beidou OTA test software used in control center according to the interface in Sect. 2 and the procedure in Sect. 3, with screen shot as Fig. 4.

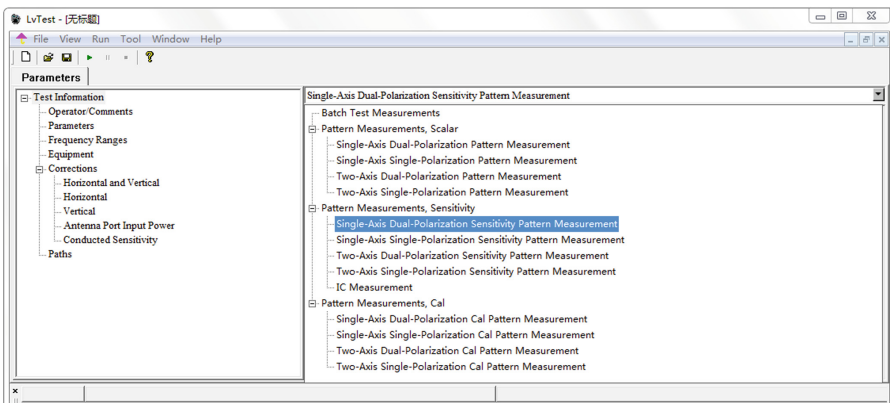


Fig. 4. Beidou OTA software

For standalone BDS, two applications based on android and windows phone platform respectively are developed to loop back standalone BDS information. In our system, two methods are used, one using USB to optical fiber; the other using Wi-Fi, both through TCP/IP protocol, as shown in Fig. 1. For USB method, we developed a customized box with size $20 \times 15 \times 2.5$ cm to replace the laptop, which can be put under absorbing materials to avoid interference (Fig. 5).



Fig. 5. Customized box to transmit data to control center

The entire Beidou OTA test system is developed based on ETS AMS 8600 chamber. The NSS8000 satellite simulator from National University of Defense Technology is used (Fig. 6).



Fig. 6. Beidou OTA test system based on 8600 chamber

From the intelligent terminals declared supporting BDS in market, all of which only support standalone BDS, we choose 17 terminals and test their standalone BDS OTA performance. For these 17 terminals, the sensitivity results are shown in Figs. 7 and 8.

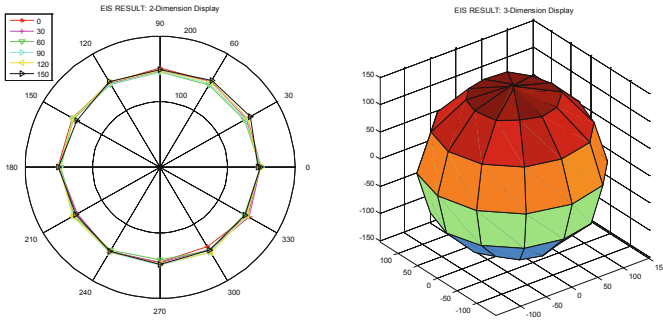


Fig. 7. 3D isotropic sensitivity

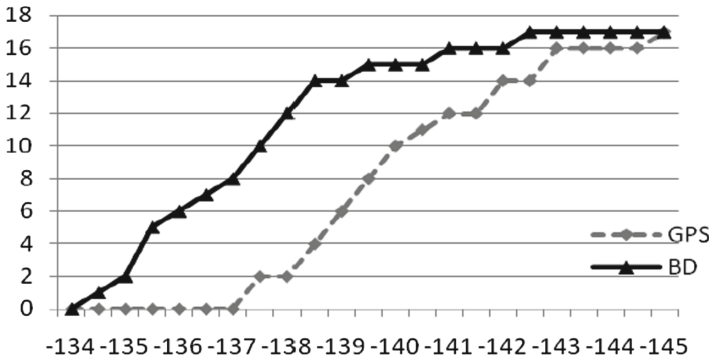


Fig. 8. GPS/BDS TIS results

From the results, we found that the overall OTA performance of the BDS is relatively poor compared to GPS, which is about 3 dB lower than that of GPS. The design principle of the majority of intelligent terminals location algorithm is that GPS is the main method while Beidou is supplemented. In particular, chip channel resource is allocated to GPS satellite in priority, which led to poor Beidou performance. In sight of national security and user experience, when GPS is not available, Beidou navigation and positioning must also be able to meet the basic user requirements.

In view of the current situation, it is urgent to speed up the standardization of Beidou navigation and positioning for intelligent terminals, including standalone mode and assisted mode. Moreover, considering the actual problem, it is also urgent to guarantee Beidou positioning performance without GPS to realize “real” Beidou positioning.

5 Conclusion

This paper introduces a Beidou OTA performance testing method for intelligent terminals, which can reflect 3D antenna sensitivity performance of the terminals. According to the proposed method, a test system is developed based on which 100 Beidou intelligent terminals are tested. Results show that most of them only support Beidou and GPS dual constellation positioning while only a small number of them support Beidou standalone positioning without GPS but their performance is relatively poor. Thus, it is urgent to speed up the standardization of Beidou navigation positioning for intelligent terminals and promote “real” Beidou positioning at current situation.

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