Design and Realization of Automatic Test System for Anti-Jamming Performance of GNSS Receivers

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Abstract. The performance test is a key part of the anti-jamming the global navigation satellite system (GNSS) receivers in researching and production. To solve the big workload and cumbersome in performance tests, an automatic test system is proposed in this paper. This system, whose core part is software which designs in Microsoft Visual Studio, can automatically control jammer, holder and anti-jamming antenna. The test software can automatically receive data from the navigation receiver and the anti-jamming antenna, can automatically statistics the carrier to noise ratio (CNR) and position information, also can automatically monitor the jam to signal ratio (JSR) in real time. Taking the CNR and the position information as anti-jamming performance test indicators, the software can automatically control the radio frequency (RF) power of jammer by setting the start, stop and step values of the jammer power. The test result shows that it can realize the automatic test after setting the necessary parameter. Also, it can automatically generate test report after completing the test. This system improves the efficiency of the anti-jamming performance test of GNSS receivers.

1. Introduction

The global navigation satellite system (GNSS) receiver anti-jamming test is an important part of the study in anti-jamming. However, the test is a tedious work, which needs monitor the jammer power and receiver. Anti-jamming antenna uses antenna array usually, which involves direction, so it is necessary to test the direction. At the same time, transmitting power of jammer needs to be adjusted constantly[1].

Domestic study is not developed in anti-jamming. So far, outdoor anti-jamming performance test is still manual. Usually, the test needs three operators at least. The first operator adjusts the power of the jammer. The second operator observes positioning results or the carrier to noise ratio (CNR) from receiver and records data. The last operator is responsible for monitoring the jammer and controlling holder. This test method is extremely inefficient.

To improve efficiency, an automatic test system is proposed in this paper. This system, in which control software acts as the core, combines jammer, holder, anti-jammer antenna, receiver and other equipment organically. All kinds of test results are recorded in real time. Finally, it can generate test report automatically. This system improves efficiency vastly[2].

2. System construction

2.1 Key part of the system

Block diagram of Automatic test system is shown in figure 1.
Key components are shown as follows.

(1) Jammer. It is used for generating jam signal. The transmitting power is between -100 dBm and 20dBm. The frequency varies from 2kHz to 6GHz. It is equipped with ARB function, which can be programmed to generate arbitrary waveforms.

(2) Power Amplifier. The jammer can transmit maximum power is only 20 dBm. In order to increase transmitting power, the power amplifier, which is connected after the jammer, is needed. The gain is 40dB. The maximum output power can be to 40dBm. The frequency range can be from 800MHz to 2GHz.

(3) Holder. It is used for testing the direction performance of antenna arrays. The azimuth, which can set in 0 to 360 °, and pitch, which can set in -40 to 40 °, are controllable. Cruise function is provided by programming, which can set azimuth angle in 0 → 360 → 0 ° circularly.

(4) Low Loss Cable. To reduce link loss, low loss cable is used between power amplifier and transmitting antenna. Which loss below 12dB/100m.

(5) Jammer Antenna. Antenna is erected on the racket, which height can be controlled by computer. It can adjust the pitch of the jamming signal. The beamwidth of antenna above 100°. The style of polarization is right-handed.

2.2 Automatic test software
The test software is the core of the anti-jamming test. The main interface is shown in figure2[3].
(1) Control Features. It can control the jammer generate various signals. It switches the positioning mode of receiver and statistic data. Adjust the azimuth and pitch of the holder, or set up automatic cruise mode. It also can control the bracket to adjust the pitch of jam.

(2) Display Features. The main interface display CNR and location information visually. The output power, modulation and signal type are displayed in the menu of jammer monitoring. The information of the jammer and its location is displayed in G-Display menu in real time.

(3) Store Features. The jammer power, holder angle, residual power, location information, CNR and the number of visible satellites is stored in real time. It is helpful to analysis or improve the performance of anti-jamming.

(4) Test Features. It can statistic the CNR and position accuracy in automatically. It also can test the anti-jamming performance automatically.

2.3 Link calculation
Link calculation determines the accuracy of anti-jamming performance directly. Free space loss is calculated as follows[4-5].

\[
FSL = 10 \log \left( \frac{4\pi r}{\lambda} \right) = 92.44 + 20 \log r + 20 \log f
\]  

(1)

In equation (1), \( \lambda \) is the wavelength of the jammer signal, and the units is m. \( f \) is the frequency in GHz. \( r \) is the propagation distance in km. In B3 frequency (1268.52MHz) of Beidou as an example, according to the jammer output power is 0dBm. The attenuation of link is as follows.

| Link                        | Gain | Level |
|-----------------------------|------|-------|
| Jammer output power         | 0dBm |       |
| Power Amplifier             | 40dB | 40dBm |
| Low Loss Cable (50m)        | -6dB | 34dBm |
| Jammer Antenna              | 3dB  | 37dBm |
| Space attenuation           | -50dB| -13dBm|
| Last Level                  |      | -13dBm|

Table 1 shows that the receiver antenna aperture interference level is up to -15dBm. According to the power of satellite signal is -131dBm when it reaches the ground[6]. This system can output a maximum the jam to signal ratio (JSR)=−13−(-131) =118dBc, which can meet the test requirements in this stage fully. With the development of anti-jamming technology, if it needs more output JSR, it can replace the high-gain antenna instead the 3dB gain antenna.

3. Key technologies

3.1 Automatic calibration level
After completing the structure of jamming scenario, system must calibrate the level. The linear relationship between the output power and the JSR is from calibration. The JSR can be computed from jammer output power during the test. Because three links are different, each of them must calibrate separately. Calibration process is shown in figure 3.
The purpose of calibration is to obtain a JSR value when the jammer output power is -30dBm. The jammer power gets from AD value through automatic calibration. 

\[ P_J = P_{\text{AD}} - P_V \] 

\[ = 20 \times \log_{10}\left(\frac{\max\left(AD_i\right)}{2^{16}} \times V_p\right) - 20 \times \log_{10}\left(\frac{\max\left(AD_i\right)}{2^{16}} \times V_p\right) \] 

(2)

In equation (2), the effective number of bits for the AD is 16bit. \( AD_i (1 \leq i \leq 4) \) is the AD value when jammer output power is -30dBm. \( AD_i (1 \leq i \leq 4) \) is the value when jammer is closed. \( V_p \) is the peak to peak value of AD. It can get \( JSR = P_J - (-131) \) when jammer output power is -30dBm. Because the output power and JSR are linear relationship, it can comput the jammer output power \( P_{\text{out}} = (-P_J - 91)\text{dBm} \) when the \( JSR = 70\text{dBc} \) [7].

3.2 Generating and controlling the jammers

Agilent E4438C is an example to generate jammer signal (Rohde&Schwarz jammer has the same principle). ARB function can generate arbitrarily waveforms through MATLAB. Generating Gaussian broadband is an example.

Step 1: Generate orthogonal Gaussian white noise signal in full band.

Step 2: Design a low-pass FIR filter for Gaussian white noise signal. It can obtain a center frequency of 0 and 20MHz bandwidth Gaussian wideband signal. The bandwidth of the FIR filter determines the bandwidth of the Gaussian wideband signal.

Step 3: The baseband signal is sent to the E4438C jammer via the LAN interface. The baseband signal is stored and modulated into a radio frequency. Then it set the default radio frequency in 1268.52MHz (Beidou B3 frequency) and transmitting power in -30dBm.

Step 4: Test software calls the generated jammer pattern, and set the radio frequency power.

The same method can be used to generate an arbitrary interference pattern, such as the spread of broadband, sweep jamming, pulse jamming, and so on.

In the process of test, software control frequency and power of jammer via LAN, which for a fixed jammer pattern, such as bandwidth 20MHz broadband Gaussian jammer. The form of jammer control is shown in figure 4.
If it needs to test automatically, software can automatically adjust the output power.

3.3 Judging the limitation performance
The limitation of judgement can determine the performance of anti-jamming test directly. Table 2 shows evaluation criteria of limitation.

Table 2. Evaluation Criteria of Limitation.

| Evaluation Criteria       | Value   |
|---------------------------|---------|
| All CNR                   | <28dBHz |
| Visible Satellite         | <4      |
| Elevation Error           | >100m   |
| Horizontal Error          | >100m   |

CNR, which is less than 28dBHz, often regards as a weak signal. If the CNR for all the channels are less than 28dBHz, we considered that the receiver has achieved the limitation. The 28dBHz is a typical value, which is related to the sensitivity of receiver. But some high-performance receivers still can position when CNR is less than 28dBHz. Different receivers have different value. If the number of visible satellites is less than 4, the receiver cannot position properly. Positioning elevation, which is a sensitive data, has a wide range firstly. If it needs to position precisely, the elevation error needs to be evaluation criteria of anti-jamming limitation. Horizontal positioning data is less sensitivity than elevation, but the evaluation criterion is similar to the elevation. In actual test, one or more, which in table 2, can be selected.

4. Test process
The limitation performance of anti-jamming test process is shown in figure 5.
During the test process, the level calibration can provide the accurate JSR value. To test the performance of the antenna arrays direction, it needs open holder cruise mode. Jammer output power increase step by step, until the receiver achieves the limitation.

To analysis conveniently, some graphs can be presented in the output report. The list of the graphs is shown in table 3.

| Graph                          | Function                              |
|-------------------------------|---------------------------------------|
| Position in different JSR     | Analysis the performance of static state |
| CNR in different JSR          | Analysis the performance of static state |
| AD power in different JSR     | Analysis the performance of static state |
| Residual power in different JSR | Analysis the performance of static state |
| Residual power in different azimuth | Analysis the performance of static state |
| CNR in different azimuth      | Analysis the performance of static state |

5. Test verification
This system tests anti-jamming performance of Beidou receiver (B3 frequency). Three jammers, which belong to Gaussian broadband signal, are set. The bandwidth is 20MHz and the center frequency is 1268.52MHz. When all channels’ CNR are below 30dBHz, the receiver achieves the limitation. The start JSR sets 40dBc and the jammer step is 3dBm. Increase power step by step, until the receiver achieves the limitation. Each scenario counts 100 times.

The first satellite in Beidou constellation is the geostationary earth orbit (GEO) satellite. The satellite signal power does not change in a fixed point. The CNR in different JSR is shown in figure 6.
Figure 6 shows that the CNR presents a downward trend with the increase of JSR. When the JSR reaches 67dBc, CNR decreases to 27.53dBHz and receiver loss of lock, and the CNR has reach the limitation that sets below 28 dBHz. The test result is that the anti-jamming performance is JSR=67dBc.

The above receiver is tested by manual and automatic method separately. The time of each step is shown in table 4.

|                      | Manual (s) | Automatic (s) |
|----------------------|------------|---------------|
| Init                 | 30         | 30            |
| Calibration Level    | 237        | 40            |
| Track Signal         | 10         | 10            |
| Test                 | 1650       | 1100          |
| Report               | 120        | 5             |
| Sum                  | 2047       | 1185          |

Above table shows that test efficiency is improved obviously, because the test time, which compare with manual method, is cut down 42%.

6. Conclusion

GNSS receivers may face increasingly the complex electromagnetic environment. This paper follows the principle of automatic tests. It starts from the construction of the test system and the key technologies. An automatic test system is proposed and implemented. The key technologies, including level calibration, generating jammer, controlling jammer and test process, are focused in the system. During the test, the computer adjusts the parameters automatic and presents the results graphically, and then output the report. This system makes test work from complex and cumbersome to quick and easy, and has an important value to study anti-jamming receiver.

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