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Test Plan for Anti-Jamming System Performance Evaluation

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ABSTRACT

With the increase in the risk of GPS jamming, the development and application of anti-jamming GPS techniques have been actively performed. As the objective performance verification of developed techniques is important, equipment development for verification and discussion on anti-jamming performance test method and procedure have also been conducted. However, most tests are related to the specification of equipment and therefore detailed procedure of the performance verification of an anti-jamming system needs to be developed. In this study, requirements for anti-jamming performance verification were described, and test configurations and performance evaluation items depending on three kinds of test methods (lab test, basic outdoor test, and chamber test) were suggested for anti-jamming performance verification.

Keywords: GPS, anti-jamming, procedure, lab test, basic outdoor test, chamber test

1. INTRODUCTION

Global Positioning System (GPS) is a navigation device that provides three-dimensional position and time information at any place around the globe using a number of middle earth orbit satellites, and it was developed in the early 1970s by the U.S. Department of Defense. Based on the calculation of precise user position by receiving more than four satellite navigation signals among more than 24 satellites located outside the Earth's atmosphere, GPS has been used in various fields such as land, sea, and aviation sectors for military and civilian purposes. In particular, in the modern national defense field, GPS is used in most weapon systems ranging from military aircraft, tank, vessel, and communication equipment to surveillance/reconnaissance equipment or precision guided munition, and thus the importance and applicability have continuously increased. However, GPS satellites transmit signals from locations that are about 20,000 km away from the Earth. Accordingly, it has very weak receiving sensitivity, and is vulnerable to interference and intentional jamming (Parkinson & Spilker 1996, Kaplan & Hegarty 2006). Fig. 1 shows the influence range of a GPS receiver depending on the strength of a GPS jamming signal. As shown in Fig. 1, for a GPS receiver using C/A code, a jamming signal with a size of 0.1 W can induce reception problems within a 70 ~ 80 km radius range from the jamming signal. Thus, although jamming or interference with a relatively low electric power is applied, navigation and national communication network could have serious problems if the interference source is close to a GPS receiver; and GPS jamming signals generated for military purposes could deteriorate the performance

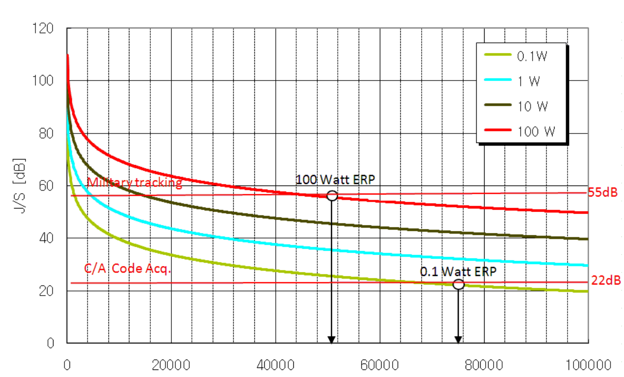

Fig. 1. J/S for distance from jammer to receiver.

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of a GPS receiver or could make a receiver inoperable (Kim 2013). Also, even though GPS can be used, the original function could not be obtained due to intentional jamming and interference. This risk of GPS usage has continuously increased; and in South Korea, the time errors of mobile communication devices and the errors of aircraft navigation devices occurred due to the intentional GNSS jamming from North Korea, as summarized in Table 1 (Lim 2013). Therefore, techniques for preventing and minimizing national level damage due to GPS jamming signals have been developed, and the development and application of various anti-jamming techniques (e.g., strengthening receiver anti-jamming capability and increasing satellite signal power) have also been performed for military weapon systems (Hu & Wei 2009, Wang et al. 2010, Lim 2013). In addition, as the objective performance verification of developed techniques is important during the development and actual application of anti-jamming techniques, equipment development for verification and discussion on anti-jamming performance test method and procedure using this have also been conducted. However, most contents are related to equipment standard and test environment, and thus, detailed procedure of the performance verification of an anti-jamming system needs to be developed (Rash 1997, Shin et al. 2008).

Therefore, in this study, requirements of the system design for the performance verification of an anti-jamming GPS system were described, and test procedures depending on three kinds of test methods (lab test, basic outdoor test, and chamber test) were suggested for anti-jamming performance verification. In Chapter 2, general anti-jamming GPS system and performance requirements are described; and in Chapter 3, a lab test, a basic outdoor test, and a chamber test are explained and necessary test configurations and test standards are suggested. Also, the conclusions are included in Chapter 4.

Table 1. Local damage cases caused by jamming.

Date	'10.8.23~26	'11.3.4~14	'12.4.28~5.13
Source	Kaesong	Kaesong, Haeju	Kaesong
Jamming signal power (dBm)	-70 ~ -60	-60	-80 ~ -60
Area of influence on jamming signal	Capital area's northwest 181 2G and WiBro base station 15 aircrafts 1 naval vessels	Capital area's northwest and Gangwon 145 2G and WiBro base station 106 aircrafts 3 naval vessels 7 vessels	Capital area's northwest 64 2G and WiBro base 1,016 aircrafts 317 vessels

Table 2. Summarizes performance comparison of the three GPS anti-jam techniques.

Anti-jam signal processing techniques	Jammer rejection performance (dB)	Cost/ Complexity	Implementation
Adaptive antenna processing	30 ~ 50	High	Analog/Digital
Precorrelation processing	20 ~ 30	Very low	Digital
Postcorrelation processing	10 ~ 15	Low	Digital HW/SW

2. PERFORMANCE REQUIREMENTS OF ANTI-JAMMING GPS SYSTEM

To establish requirements for the design of an anti-jamming GPS system, various aspects need to be considered such as cost, effect, and system performance. For an anti-jamming GPS technique, diverse methods can be developed at various points of a receiving system, but the structure of a necessary anti-jamming system could vary depending on mission, the characteristics of threatening signals to be dealt with, and available techniques. All these requirements need to be verified in a test for the performance verification of an anti-jamming GPS system, and thus, determination of requirements is important. In this chapter, a general anti-jamming GPS device was explained, and performance requirements to be determined during design were described by dividing them into GPS receiving band, JSR, the number of jammers that can be dealt with, and jammer type.

2.1 General Anti-jamming GPS System

The anti-jamming processing of an anti-jamming GPS system can be broadly classified into adaptive antenna processing, precorrelation processing, and postcorrelation processing. The adaptive antenna processing eliminates RF jamming by using multi-array antennas and a dedicated process for null steering and beam forming control. For the precorrelation processing, a filter processing technique is added to the front end of a correlator within a GPS receiver. The postcorrelation processing eliminates jamming by changing the signal tracking part of a GPS receiver without the modification of hardware. Table 2 summarizes the performance and cost of each anti-jamming processing. As summarized in Table 2, in general, the largest anti-jamming effect can be expected for adaptive antenna, which uses Controlled Reception Pattern Antenna (CRPA) and Anti-jam Electronics (AE) (Dimos et al. 1995). Thus, the anti-jamming GPS system has a structure shown in Fig. 2. As shown in Fig. 3, using CRPA which is an array antenna, nulling is performed which suppresses a jamming signal by forming null in

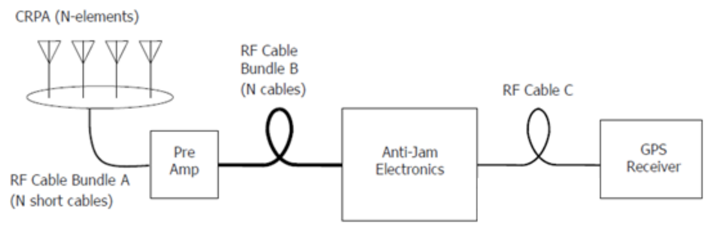

Fig. 2. Anti-jamming GPS system.

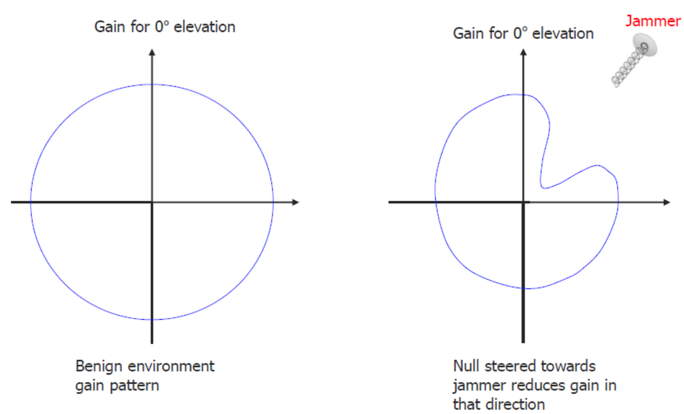

Fig. 3. Null steering technique.

the jamming signal direction. This jamming elimination is processed by AE, and it is classified into GPS receiver separated type or integrated type depending on the possibility of linkage with an existing GPS receiver. When it can be linked with an existing GPS receiver, a GPS receiver and AE are separated, and AE performs the anti-jamming function. The RF up-conversion of the anti-jamming treated GPS signals is again performed, and a single RF signal is outputted through an RF coaxial cable. On the other hand, when it is not linked, a GPS receiver and AE are integrated, the GPS receiver and CRPA are directly linked, and the GPS receiver performs the anti-jamming function (Dimos et al. 1995, Kim 2013).

2.2 Performance Requirements

The performance requirements of an anti-jamming GPS system can be broadly divided into JSR, jamming signal type, and the number of jammers that can be dealt with. Each element is explained as follows.

2.2.1 Jamming to Signal Ratio

For GPS anti-jamming performance, the maximum anti-jamming capability of an anti-jamming GPS system is generally expressed based on a Jamming to Signal Ratio (JSR) value. This is the only method that expresses the performance of constituent parts excluding various external environments that could occur during actual operation, and is a test method that is basically performed. JSR is calculated as the ratio of jamming signal strength to GPS signal strength, as shown in Eq. (1).

$$\mathrm{JSR} = G_P - \left[L_{sys} + \left(\frac{S}{N}\right)_{out}\right] \tag{1}$$

where G_P is the baseband processing gain, L_{sys} is the internal loss of the GPS receiver, and S/N_{out} is the SNR_{out} required for Binary Phase Shift Keying (Kim & Bae 2006). In other words, it indicates that if there is an interference signal that is J/S dB higher than the GPS signal received from satellites, a normal data demodulation function for satellite navigation cannot be performed.

J/S is determined by the anti-jamming technique applied to an anti-jamming GPS system, and Table 3 summarizes generally known anti-jamming performances (Dimos et al. 1995).

2.2.2 Number of Jammers that Can be Dealt with

The number of GPS jammers that can be simultaneously dealt with is related to the number of elements for an array antenna. The number of elements for an array antenna is identically set to the number of channels for the electronic part, and the number of array antennas could vary depending on the operation environment. The electrical characteristics of an antenna deteriorate as the

Table 3. Jamming source of GPS.

Interference type		Typical interference source
Wide band	Gaussian	Intended noise jammer
	Expended frequency	Intended expended frequency jammer
Narrow band	Continuous wave	Intended continuous wave jammer
	Swept continuous wave	Intentional CW jammer Harmonics of FM broadcast transmitter
	Hot noise	Noise caused by the instruments of circuit

Table 4. GPS Anti-jam system performance tests.

Item	Requirements
JSR	< xx dB
Type of jamming source	Wideband jamming signal - AWGN (1575 MHz, BW 2 MHz)
	Narrowband jamming signal - CW, pulse (1575 MHz)
Number of jammer	N-1

size decreases, and thus, there is a trade-off relationship between performance and size. A large aircraft can use seven-element array antenna; but for a small aircraft or a weapon system, four to five elements have been developed and applied in developed countries considering the installation and operation. The number of elements for an array antenna is related to the number of jammers that can be simultaneously dealt with. It is generally known that when the number of elements for an array antenna is N, N-1 jammers can be dealt with (Kim 2013). In other words, when four elements are used, up to three jamming signals can be simultaneously eliminated. More than N CW or narrowband jamming signals could be eliminated depending on the anti-jamming technique; but for wideband jamming signals, at least N-1 jamming signals could be eliminated.

2.2.3 Jamming Signal Type

In general, GPS jamming signals that are introduced to a GPS receiver can be broadly classified into wideband jamming and narrowband jamming, as summarized in Table 3. The wideband jamming indicates that wideband modulated signals have an effect over a general spread signal band. It is a jamming signal with a bandwidth of 100 kHz ~ 20.46 MHz, and consumes a lot of electric power and cost. Representative wideband jamming includes Gaussian noise, and this prevents the recognition of jamming by applying random characteristic noise that follows the Gaussian distribution. On the other hand, narrowband jamming applies jamming to a relatively narrow predetermined frequency band, and has a bandwidth of 1 kHz ~ 100 kHz. Narrowband jamming performs jamming in a random order or a sequential order (i.e., swept jamming), and generates tone or narrowband jamming signals by applying continuous waves. Also, it could perform multi-narrowband jamming (Armor 1998, Hua et al. 2008, Kim 2013).

3. TEST PLAN OF ANTI-JAMMING GPS SYSTEM

For an anti-jamming GPS system, JSR, jamming signal type, and the number of jammers that can be dealt with need to be verified based on the performance requirements explained in Section 2. Table 4 summarizes the items that need to be verified accordingly. When the determined required performance JSR is more than xx dB and the strength of jamming signals introduced to a GPS receiver is GPS signal -130 dBm, a test is performed to examine if the GPS receiver normally operates at about $-\triangle$dB (= - 130 - (- xxdB)). Also, a test is performed for each determined jamming signal type, and it is examined if the receiver performs normal navigation when the maximum number of jamming signals that can be dealt with was introduced. These tests can be performed by dividing them into a lab test, a basic outdoor test, and a chamber test. In the lab test, through simulation in a laboratory environment, it is examined if normal navigation is performed when the maximum jamming signals are applied to an anti-jamming GPS system. In the basic outdoor test, a basic function test is performed to examine if the anti-jamming function operates when jamming signals are applied while actual GPS signals are received in an outdoor environment. In the chamber test, an actual installation environment is simulated by arranging a number of jammers within an anechoic chamber, and the maximum jamming signals are applied to an anti-jamming GPS system. Then, normal operation of navigation is examined. To perform this performance evaluation, test equipment that electrically simulates GPS satellite signals and jamming signals is required. For this purpose, anti-jamming test equipment was developed, and a test bed for anti-jamming performance evaluation was established. In Section 3.1, test equipment necessary for evaluation is described; and in Section 3.2, test environment configuration and procedure for each test are explained.

3.1 Test Equipment of Anti-Jamming GPS Performance Evaluation

Anti-jamming test equipment can evaluate anti-jamming performance through anti-jamming GPS system (CRPA/AE) performance/test evaluation, GPS jamming/anti-jamming GPS system outdoor test device configuration and data acquisition, and jamming test configuration within an electromagnetic wave anechoic chamber and

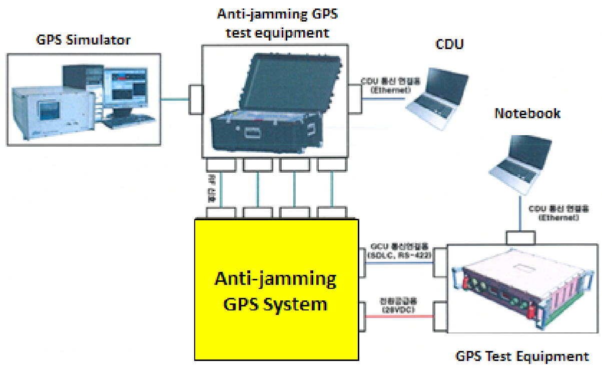

Fig. 4. Lab test environment configuration.

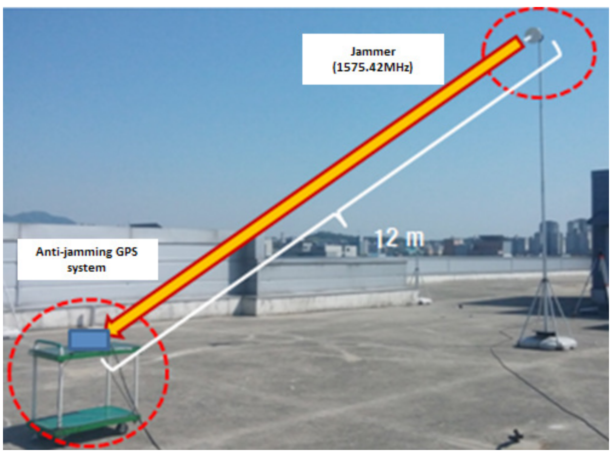

Fig. 5. Basic outdoor test environment configuration.

data acquisition. To evaluate anti-jamming performance, a GPS simulator that simulates GPS signals; anti-jamming GPS test equipment that simulates the incidence of various types of virtual jamming signals, combines them with GPS signals, and outputs as RF; and Control Display Unit (CDU) that controls this test equipment are required. Table 5 summarizes the test equipment for the evaluation of anti-jamming performance. The configuration of the test was described for each test.

3.2 Lab Test

The lab test measures the anti-jamming capability of an anti-jamming GPS system through simulation in a laboratory environment, and uses a GPS simulator and anti-jamming GPS test equipment. Fig. 4 shows the test environment configuration of the lab test. The GPS simulator simulates GPS signals, and the anti-jamming GPS test equipment outputs RF signals by simulating a phase plane as if jamming signals were introduced. Also, CDU can control the test scenario, jamming type, and jamming strength. Table 6 summarizes the test standard of the lab test.

Table 5. List of test equipment for anti-jamming performance.

List	Functions
GPS simulator	Output GPS or GNSS signal using GPS simulator
Anti-jamming GPS test equipment	Output simulated jamming signal to RF port
Control/Display Unit (CDU)	Scenario setting test equipment control Data output interface
Notebook	Control/Monitor the anti-jamming GPS system
Cables	RF/communication/power cables

Table 6. Test standard of the lab test.

Requirements	Jamming signal	Criterion
Anti-jamming performance > xx dB	GPS L1 or L2C CW (1575 MHz, -xx dBm) GPS L1 or L2C CW (1575 MHz, -xx dBm, AWGN)	Track more than 4 GPS L1 or L2C satellites

When a GPS or GNSS signal is introduced to the test device for anti-jamming satellite navigation verification, the test device introduces an RF signal to the anti-jamming GPS system by simulating as if one jamming signal was introduced. In this regard, the type or strength of the jamming signal is determined by the requirements, and can be controlled using CDU. A test is performed to examine if the anti-jamming GPS system can normally perform 3D navigation by tracking more than four satellites when jamming signals are introduced as described above.

3.3 Basic Outdoor Test

The basic outdoor test is performed in an environment where actual GPS signals are received. For the test, a directional antenna that transmits jamming signals, and a jamming signal generator are used, as shown in Fig. 5. The test standard of the basic outdoor test is identical to that of the lab test. A test is performed to examine if the anti-jamming GPS system performs normal navigation when jamming signals are applied based on the strength and type of the jamming signal defined in the requirements.

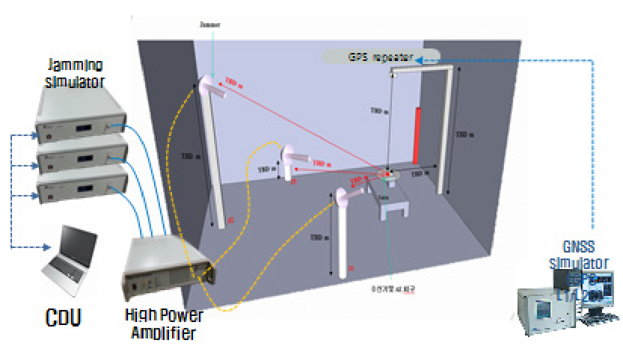

Fig. 6. Chamber test environment configuration.

Table 7. Test standard of the chamber test.

Requirements	Jamming signal	Number of jammers	Criterion
Anti-jamming performance > xx dB for 3 jammers	GPS L1 or L2C CW (1575 MHz, -xx dBm)	1	Track more than 4 GPS L1 or L2C satellites
	GPS L1 or L2C CW (1575 MHz, -xx dBm, AWGN)	1	
	GPS L1 or L2C CW (1575 MHz, -xx dBm)	2	
	GPS L1 or L2C CW (1575 MHz, -xx dBm, AWGN)	2	
	GPS L1 or L2C CW (1575 MHz, -xx dBm)	3	
	GPS L1 or L2C CW (1575 MHz, -xx dBm, AWGN)	3	

3.4 Chamber Test

The chamber test is performed by simulating an actual installation environment within an anechoic chamber. For this purpose, multiple jammer signals are applied using a GPS simulator, a jamming signal simulator, and CDU that controls the type or strength of a jamming signal, as shown in Fig. 6. Then, verification is performed to examine if the anti-jamming GPS system can track more than four satellites and can perform normal navigation with respect to the maximum jamming signal strength. Table 7 summarizes the test standard of the chamber test when four-element CRPA is used.

For the GPS signals in the chamber test, GPS signals are rebroadcasted from the ceiling using a GPS repeater installed inside the chamber, and this is different from an actual receiving environment. If a jamming signal is aligned with the GPS signal radiation direction on the same line, a GPS signal cannot be received, and thus it needs to be considered during the determination of the jamming signal direction. If a jamming signal is too large and affects the part that radiates GPS signals, the anti-jamming performance could deteriorate, and thus the position of the jammer needs to be determined considering the environment.

4. CONCLUSIONS

In this study, for the performance verification of an anti-jamming GPS system, the performance requirements of the system were described, and test items and procedures for performance verification were suggested. The tests for performance verification were divided into three kinds of tests (lab test, basic outdoor test, and chamber test), and the verification items were defined as JSR, jamming signal type, and the number of jammers that can be dealt with, depending on each test environment. To perform this performance evaluation, test equipment that electrically simulates GPS satellite signals and jamming signals is required. In this study, anti-jamming test equipment for this purpose was developed, and a test bed for anti-jamming performance evaluation was established. Also, test configuration and test standard for each test were defined. In the future, performance evaluation of an anti-jamming GPS system will be carried out.

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