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Jamming Effect Analysis of Two Chinese GNSS BeiDou-II Civil Signals

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ABSTRACT

Threats of electronic warfare, especially to global positioning systems (GPSs), have been rapidly increasing. The development of the Chinese navigation satellite system BeiDou has been extended to a global navigation satellite system (GNSS). In December 2011, the Chinese government released a specification document-a test version of a civil BeiDou-II signal called B1(I). A strong possibility exists that BeiDou-II (Chinese GNSS) will be adopted by North Korea in the near future. Therefore, research on BeiDou-II is essential. Since BeiDou-II is a newly-built system, few jamming effect analyses of its positioning signals have been performed. Thus, in this study, we analyze quality factors (Q) and the tolerable jamming signal power among two BeiDou-II civil signals, and two GPS civil signals, in three jamming conditions: band-limited white noise (BLWN), matched spectrum (MS), and continuous wave (CW). In addition, we present each jamming propagation range.

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1. INTRODUCTION

In 2011, global positioning system (GPS) jamming signals thought to have been transmitted by North Korea were detected in the capital area of South Korea. Due to the electronic attack, fatal errors occurred in commercial communications networks and systems that need timing synchronization [1]. As a result, demands have been rapidly increasing for securing the positioning accuracy and reliability of global navigation satellite systems (GNSSs) in jamming circumstances. To achieve this, sufficient methodical studies must be performed on the jamming effect for representative GNSS civil signals with various type of jamming.

Moreover, the Chinese navigation system BeiDou, also known as COMPASS, has been developed since the early 2000s. Since there is a strong possibility that BeiDou-II (Chinese GNSS) will be adopted by North Korea in the near future, research on BeiDou-II is essential. However, thus far, there has not been enough information on the systems to conduct research and analysis. In December 2011, the Chinese government released a specification document of the BeiDou-II civil signal, called B1(I), in [2]. This was a test version and not an official version.

BeiDou-II adopts a multiplexed binary offset carrier (MBOC) signal called B1-C_D. MBOC signals are widely known as representative of modernized civil positioning signals such as GPS L1C (L1 Civil) and Galileo E1 OS (open service). Very little information about BeiDou-II B1-C_D has been released (e.g., carrier frequency, bandwidth, spreading chip rate, modulation scheme, data rate, and symbol rate) [3].

In this study, we analyze the effects of a jamming signal on two Chinese GNSS civil signals, BeiDou-II B1(I) and B1-C_D. We considered three types of jamming circumstances-band-limited white noise (BLWN), matched spectrum (MS), and continuous wave (CW) jamming. To analyze the effect of jamming, we evaluated a dimensionless jamming resistance quality factor Q, which is an indicator of signal robustness against jamming. In addition, the tolerable jamming power level and jamming propagation range were obtained within the BLWN, MS, and CW jamming circumstances. For an objective analysis, we compared the results of the BeiDou-II signals and two representative GNSS signals, GPS L1 course/acquisition (C/A) and GPS L1C.

2. SIGNAL SPECIFICATION, JAMMING, AND PARAMETER

2.1. Signal Specification

The main specifications of signals BeiDou-II B1(I), B1-C$_D$, GPS L1 C/A, and GPS L1C are shown in Table 1 [2-4]. The C/A, B1-C$_D$, and L1C signals have the same chip rate, but B1(I) has a chip rate that is twice as high as the others. Also, the C/A, B1-C$_D$, and L1C signals have the same center frequency, 1575.42 MHz, whereas B1(I) has a center frequency of 1561.098 MHz. Both the B1(I) and C/A signals use binary phase shift keying (BPSK) modulation, whereas B1-C$_D$ and L1C use MBOC modulation (especially MBOC(6,1,1/11), which has been proposed for modernized GNSS signals). Each minimum received signal power level is based on a user antenna linearly polarized with a 3 dB gain. Since there is no document available to the public describing the power level of B1-C$_D$, we assume that B1-C$_D$ has the same minimum received power level as the signals that use MBOC(6,1,1/11) (e.g., GPS L1C and Galileo E1 OS) [4]. Ed. highlight-is this what you mean? We note that the B1(I) signal has the lowest power level, and the B1-C$_D$ and L1C signals have the highest power level.

2.2. Jamming Types

Three types of jamming were considered in this study: BLWN, MS, and CW. BLWN jamming has properties including band-limited white Gaussian noise whose spectrum is rectangular, and a center frequency centered to the target signal's center frequency.

Table 1. Signal Specification

Category	**Signal type**			
	B1(I)	***C/A***	***B1-C$_D$***	***L1C***
PRN[a] code chip rate (MHz)	2.046	1.023	1.023	1.023
Center freq. (MHz)	1561.098	1575.42	1575.42	1575.42
Spreading modulation	BPSK	BPSK	MBOC$_{(6,1,1/11)}$	MBOC$_{(6,1,1/11)}$
Minimum received signal power (dBW)	-163.0	-158.5	-157.0	-157.0

a. pseudo-random noise

MS jamming has the same power spectral density (PSD) as the target signal. Thus, MS jamming could occur when the jammer transmits a signal waveform whose spectrum is matched to that of the desired signal. CW jamming has a single frequency component. The frequency of CW jamming is generally located at the center frequency of the target signal, or near the dominant component of its PSD. Moreover, if the normalized power spectrum of the target signal has a maximum value that is smaller than the jammer expected, the target signal is degraded less by CW jamming at the worst-case frequency.

2.3. Common Parameters

To analyze the effect of the aforementioned three types of jamming, the parameters shown in Table 2 were applied. The tracking threshold is the minimum C/N$_0$ value at which a tracking loop is able to maintain a stable lock [5]. J_t is the jamming transmission power, G_t is an antenna gain of the jammer, G_s and G_j are the receiver antenna gains to satellite vehicle (SV) and jamming signals, respectively, and L_f is the jammer power loss due to front-end filtering at the receiver.

3. JAMMING EFFECT ANALYSIS

3.1. Q and Tolerable Jamming Power

Using the specifications and parameters shown in Tables 1 and 2, we determined the dimensionless jamming resistance quality factor Q, the tolerable jamming power, and the jamming propagation range [5]. Q is an indicator of signal robustness to jamming. The value of Q is determined by various types of jamming signals and signal modulation schemes. When the value of Q is larger, the signal is more robust to the jamming. Q is defined as follows:

$$Q = \frac{1}{R_c \int_{-\infty}^{\infty} S_I(f) S_s(f)\, df} \tag{1}$$

where R_c is the spreading code chip rate in chips per second, $S_I(f)$ is the PSD of the aggregate interference normalized to unit area over infinite bandwidth, and $S_s(f)$ is the PSD of the signal normalized to unit area over infinite bandwidth. The PSDs for the BPSK and MBOC(6,1,1/11) modulation schemes are given by Eqs. (2) and (3), respectively [5, 6]:

$$S_{BPSK}(f) = T_c \mathrm{sinc}^2(\pi f t) \tag{2}$$

$$S_{MBOC(6,1,1/11)}(f) = \frac{10}{11} S_{BOC(1,1)}(f) + \frac{1}{11} S_{BOC(6,1)}(f) \tag{3}$$

where T_c is the chip period, and $S_{BOC(m,n)}(f)$ is the unit-power spectral density of a sine-phased BOC modulation as defined in [7]. To consider three types of jamming, Eq. (1) can be expressed in three different forms:

$$Q_{BLWN} = \frac{2R_c}{\int_{-R_c}^{R_c} S_s(f)\, df} \tag{4}$$

$$Q_{MS} = \frac{1}{R_c \int_{-\infty}^{\infty} \left[S_s(f)\right]^2 df} \tag{5}$$

$$Q_{CW} = \frac{1}{R_c S_s(f)} \tag{6}$$

where Q_{BLWN}, Q_{MS}, and Q_{CW} are values of Q within the BLWN, MS, and CW jamming circumstances, respectively. As shown by Eqs. (4)-(6), when the terms related to $S_s(f)$ become smaller, the values of Q become larger. The tolerable jamming power $(J_r)_{dB}$ is the upper limit at which the receiver can maintain a tracking loop in the presence of jamming (e.g., if $(J_r)_{dB}$ is -127.9, a receiver tracking process can tolerate a jamming power level up to -127.9 dB.) $(J_r)_{dB}$ is affected by Q, the chip rate, and the minimum received power level of SV signals. $(J_r)_{dB}$ is defined as follows:

$$(J_r)_{dB} = (J/S)_{dB} + (S_r)_{dB} \tag{7}$$

where $(J/S)_{dB}$ is the jamming-to-signal power ratio, and $(S_r)_{dB}$ is the minimum received signal power. Since $(J/S)_{dB}$ is based on the receiver tracking threshold, the tolerable jamming power is the sum of $(J/S)_{dB}$ and $(S_r)_{dB}$.

Table 2. Common Parameters

Parameter	**Value**
Tracking threshold	28 dB
J_t	1 W
G_t	3 dB
G_s	0 dB
G_j	-3 dB
L_f	0 dB

Table 3. Q and Tolerable Jamming Power (a)

Jamming	**Quality factor Q**				**Tolerable Jamming Power [dB]**			
Type	***B1(I)***	***C/A***	***B1-C_D***	***L1C***	***B1(I)***	***C/A***	***B1-C_D***	***L1C***
BLWN	2.22		4.19		-120.1	-120.1	-115.8	
MS	1.50		3.60		-123.6	-121.8	-116.5	
CW	1.00		2.09		-125.4	-123.6	-118.8	

The values of Q and the tolerable jamming power are obtained by using (1)-(2). As shown in Table 3, the B1(I) and C/A signals have the same Q values, although B1(I) uses twice the chip rate. Both signals use BPSK modulation and have the same PSD, but have different chip rates. However, those R_c values are offset during the calculation process, so that Q is only affected by modulation scheme, not by the chip rate. Similarly, B1-C_D and L1C have the same values of Q since they use the same modulation, MBOC(6,1,1/11), and they have the same chip rate. In addition, due to the spectral properties, the two signals using MBOC modulation have about twice the value of Q than the signals using BPSK modulation.

The tolerable jamming power $(J_r)_{dB}$ is largely affected by the minimum received signal power, as well as by Q. Since B1(I) has a 4 dBW lower power level, B1(I) has a lower tolerable jamming power than C/A. In addition to the same value of Q, because we assumed that B1-C_D has the same minimum received signal power level as L1C in Section II, both signals have the same tolerable jamming power. Also, signals using MBOC modulation have about a 5 dB higher tolerable jamming power than signals using BPSK modulation.

3.2. Jamming Propagation Range

Given Q and the tolerable jamming power level, the jamming propagation range can be determined for each SV signal. The range d is given by

$$d = \frac{\lambda_j 10^{(L_p)_{dB}/20}}{4000\pi} \tag{8}$$

where $_j$ is the wavelength of the jamming signals, and $(L_p)_{dB}$ is the free space propagation loss given by

$$(L_p)_{dB} = (J_t)_{dB} + (G_t)_{dB} - (J_r)_{dB} + (G_j)_{dB} - (L_f)_{dB} \tag{9}$$

B1(I) has a lower minimum received signal power level. This and wavelength affect $(J_r)_{dB}$ in Eq. (9) Thus, the jamming propagation range of the B1(I) signal is longer than that of C/A. B1-C_D and L1C have the same jamming propagation range, which is shorter than those of the other two signals. This means that B1(I) is the signal most affected by jamming-receivers could lose their positioning function under the jamming condition.

We used the Jamming Signal Spreading Simulator based on the MATLAB® graphical user interface (GUI). The jamming propagation ranges of four GNSS civil signals are shown in Figs. 1-3. Each BLWN, MS, and CW jamming circumstance was applied as Table 4. The maps in the figures show the region around the capital area of South Korea adjacent to North Korea. The dark innermost solid line represents the maximum range of B1-C_D and L1C, the dark dotted line represents the range of C/A, and the outermost light dotted line represents the range of B1(I).

Table 4. Jamming Propagation Range

Jamming Type	**Distance [km]**			
	B1(I)	***C/A***	***B1-C_D***	***L1C***
BLWN	19.0	15.4	9.3	
MS	23.1	18.7	10.1	
CW	28.3	22.9	13.2	

With BLWN jamming, the B1(I) signal is jammed about in 1.5 times larger area than that of C/A, and it is 4.2 times larger than the that of B1-C_D/L1C signals. With MS jamming, the B1(I) signal is jammed about in 1.5 times larger area than that of C/A, and it is 5.3 times larger than that of B1-C_D/L1C signals. With CW jamming, the B1(I) signal is jammed about in 1.5 times larger area than that of C/A, and it is 4.6 times than that of B1-C_D/L1C signals.

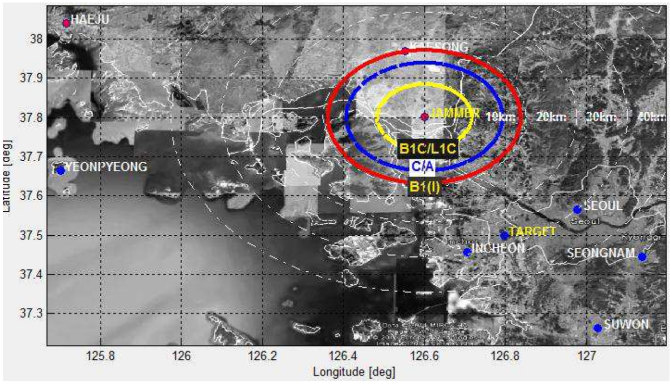

Figure 1. Jamming Propagation Range (BLWN)

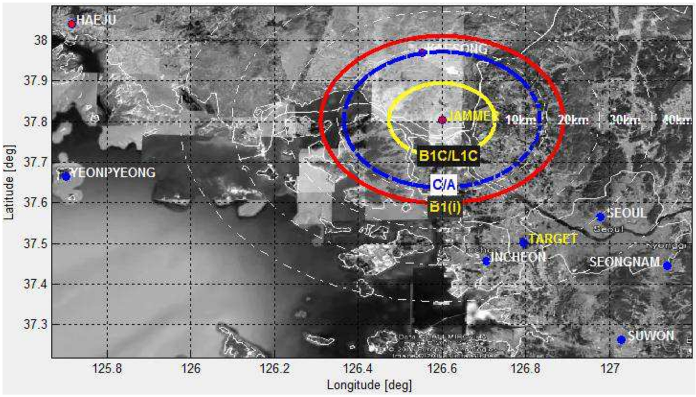

Figure 2. Jamming Propagation Range (MS)

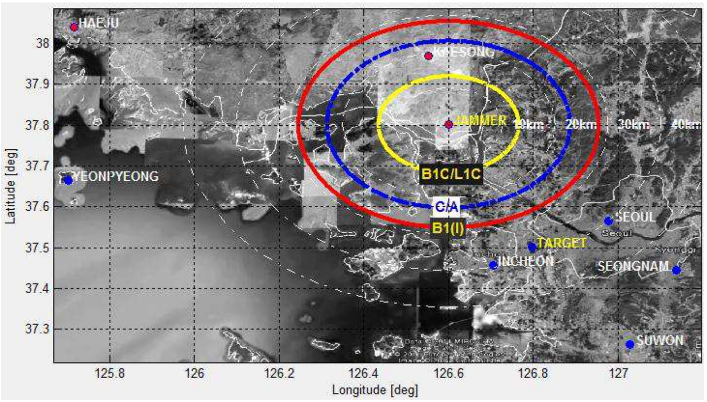

Figure 3. Jamming Propagation Range (CW)

4. CONCLUSION

We analyzed the jamming effect on two BeiDou-II civil signals, B1(I) and B1-C_D. BLWN, MS, and CW signals were used as jamming circumstances. Three factors--Q, the tolerable jamming power level, and the jamming propagation range--were determined. For an objective analysis, the data were compared to those of the representative civil signals, GPS L1 C/A, and L1C. Q depends on the modulation schemes, and is not affected by the chip rate of the signal. Thus, B1(I) and C/A, which use BPSK modulation, have the same Q. Because they use the same modulation, the MBOC(6,1,1/11), B1-C_D, and L1C signals have the same value of Q, which is larger than the values of B1(I) and C/A. Thus, signals using MBOC(6,1,1/11) modulation are more robust against jamming than signals that use BPSK.

Since the minimum received signal power level of B1(I) is lower than that of C/A, B1(I) has a lower tolerable jamming power level than that of C/A, even though B1(I) has the same Q as C/A. In addition to having the same Q, B1-C_D has the same minimum received signal power as L1C, as described in Section II. Thus, those two signals have the same tolerable jamming power level, which is higher than those of B1(I) and C/A. Due to its lower signal power level and longer wavelength, B1(I) has the longest jamming propagation range compared to other signals. B1-CD and L1C have the shortest range since they use a more robust modulation scheme to jam, and a higher signal power level. In future works, diffraction caused by topography, more jamming scenarios, and the antenna radiation pattern of the jammer need to be considered in order to improve the accuracy of the results.

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REFERENCES

[1] S. Yoo and K. Kim, “North sent GPS jamming signals to capital area of South,” *DongA-Ilbo*, [Online]. Available: http://news.donga.com/3/all/20110307/35356067/1, Mar. 2011.

[2] China Satellite Navigation Office, *Beidou navigation satellite system signal in space interface control document (test ver.)*, [Online]. Available: http://www.beidou.gov.cn/attach/2011/12/

[3] China reveals updated Compass/Beidou-2 GNSS signal plan, *Inside GNSS September/October 2009*, Aug. 2009. [Online]. Available: http://www.insidegnss.com/node/1624

[4] S. Wallner, G. W. Hein, and J. A. Avila-Rodriguez, “Interference computations between several GNSS systems,” *Proc. of the ESA Workshop on Satellite Navigation User Equipment Technologies (NAVITEC)*, Noordwijk, Netherlands, Dec. 2006.

[5] E. Kaplan and C. J. Hegarty, *Understanding GPS: Principles and Applications*, 2nd ed., Artech House, Boston, MA, 2006.

[6] F. Dovis, L. L. Presti, M. Fantino, P. Mulassano, and J. Godet, ”Comparison between Galileo CBOC candidates and BOC(1,1) in terms of detection performance,” *International Journal of Navigation and Observation*, vol. 2008, 2008. , 2008. Article ID 793868, 9 pages, doi:10.1155/2008/ 793868.

[7] J. W. Betz, "Binary offset carrier modulations for radionavigation," *NAVIGATION: Journal of The Institute of Navigation*, vol. 48, no. 4, pp. 227-246, winter 2001-2002.