MSK-BCS Modulation for GNSS Radio Frequency Compatibility in C Band

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Abstract—Due to insufficient Radio Navigation Satellite Service (RNSS) portion of Radio Frequency (RF) spectrum for many services that are being planned for the future on L band where has come up a frequency overlapping situation, C band as an alternative spectral allocation has already been proposed in the previous years. The future C band signals could make use of the frequency band between 5010MHz and 5030MHz, offering a narrow bandwidth of 20 MHz. The main goal of C band signal design aims at having band limited signals. Consequently, it should be designed with a view to compatibility in band and the power emissions out of band. The Minimum Shift Keying (MSK) modulation is investigated to provide constant envelope and a good spectrum confinement, furthermore, a Binary Coded Symbol (BCS) modulation based on MSK pulse that has sharper autocorrelation, larger Gabor bandwidth, smaller Cramér-Rao Lower Bound and less multipath error has been presented by Liu. Suppose spread interoperability signals employing the BCS modulation based on MSK pulse for Global Navigation Satellite System (GNSS) in C band with only a narrow bandwidth of 20MHz. Simulation results reveal the interference for the receiver prompt correlator channel processing and code tracking induced by navigation satellite system to each other. The result can be significant for the future signal design in C band.

Index Terms—C Band; MSK Pulse; Binary Coded Symbol Modulation; Compatibility; Degradation of Effective Carrier Power to Noise

I. INTRODUCTION

In the course of the World Radio Conference 2000 (WRC-2000) the frequency band between 5010MHz and 5030MHz offering a bandwidth of 20MHz was already allocated as C band portion for Radio Navigation Satellite Service (RNSS) applications [1]. However, the use of C band for transmitting satellite navigation signals provides both advantages and drawbacks [2]. On the one hand, the prominent merits are that C band exhibits much smaller ionosphere errors for standard single frequency applications, smaller antenna arrays and elements which may reduce vulnerability, and potentially higher jamming resistance under the same conditions as L band. Besides, C band can acquire better potential carrier phase accuracy due to smaller carrier wavelength and better speed accuracy thanks to larger Doppler with the same C / N0. On the other hand, the signal attenuation induced by free space loss, rainfall attenuation and foliage increases would be much more significant, and so the required satellite payload power of C band would be difficult to provide. It is the crucial factor not to choose C band for the first generation of Galileo, furthermore, out of band emission requirements especially for radio astronomy band are very stringent. However, progresses in electronics and spacecraft technology can balance these drawbacks. Coupled with continued proliferation of signals in L band, C band has caused great interest as a candidate for the future global navigation satellite system (GNSS) services.

The frequency slot has only a reduced bandwidth of 20MHz available with very strict limitations about compatibility in band and the power emissions out of band. So the C band signal design should aim at band limited signals. Moreover the signals based on constant envelope continuous phase modulation reveal the satisfactory characteristic that the High Power Amplifier (HPA) can run in saturation or close to saturation, increasing thus the total efficiency of the amplification. Above all, the signals with constant envelope will be better. And the Minimum Shift Keying (MSK) modulation investigated in depth [3] that presents constant envelope and relatively good spectral confinement is one of the C-band signal candidates. Based on BCS sequence with MSK pulses, Liu presented MSK-BCS [4] with better autocorrelation, multipath resistance, spectral separation, code tracking and so on. Also, the proposed MSK-BCS provides limited spectral and constant envelope. So MSK-BCS modulation meets demands of C band signal design.

In consideration of the narrow bandwidth of C band, the interoperability signals will be likely to spread in order not to cause interference in case of crowded signals. And so suppose the interoperability signals make use of aforementioned MSK-BCS modulation. Yet compatibility is a fundamental aspect in the design of any navigation signal and has higher priority than other performance. Therefore, the interoperability signals must assure respective compatibility performance first. And the compatibility in band of interoperability signals for different constellations separately using MSK-BCS put forward by Liu [4] is assessed in the paper. The assessment methodologies of degradation of effective carrier power to noise based on Spectral Separation Coefficient (SSC) and Code Tracking Spectral Sensitivity

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Coefficient (CTSSC) are utilized. And the results can reveal the interference for the receiver prompt correlator channel processing and code phase tracking.

This paper is organized as follows. Section 2 introduced the common power spectral density’s expression of MSK-BCS based on BCS sequence. Section 3 presents the compatibility assessment methodologies of degradation of effective carrier-power-to-noise density ratio based on Spectral Separation Coefficient (SSC) and Code Tracking Spectral Sensitivity Coefficient (CTSSC). And Section 4 gives the simulations for radio frequency compatibility in band of the interoperability signals with MSK-BCS modulation in C Band. Finally, Section 5 draws conclusions.

II. MSK-BINARY CODED SYMBOL MODULATION

MSK signal is a special case of the Continuous Phase Frequency Shift Keying. The normalized Power Spectral Density (PSD) of the pulse waveform for the MSK can be written as [3]

\[
G_{\text{MSK-pulse}}(f) = f_n \| \mathbf{s}_{\text{MSK}}(f) \|^2 = f_n \left( \frac{8f_n^2 \cos^2 \left( \frac{\pi f}{f_n} \right)}{f_n^2 - 4f^2} \right)^2
\]

where \( f_n \) is the frequency of a spreading code chip.

Any BCS(\{s_0, s_1, \ldots , s_{n-1} \}, f_c) sequence uses the general expression form [5]:

\[
G_{\text{BCS}[G_{f_c}]}(f) = \left\| \sum_{n=1}^{n} s_n e^{-j2\pi kf/cn} \right\|^2
\]

\[
= \left\{ \sum_{n=1}^{n} \sum_{k=-1}^{n-1} 2s_n s_k \cos \left( \frac{2\pi f}{nf} \right) \right\}^2
\]

where \( n \) is the sequence length. \( f_c \) is the frequency of a spreading code and \( f_c = \frac{f_n}{n} \).

Accordingly, the expression of PSD for BCS sequence with MSK pulses denoted as MSK-BCS(\{s_0, s_1, \ldots , s_{n-1} \}, f_c) can be written as:

\[
G(f) = G_{\text{MSK-pulse}}(f) G_{\text{MSK-BCS}[G_{f_c}]}(f)
\]

\[
= f_n \left( \frac{8f_n^2 \cos^2 \left( \frac{\pi f}{f_n} \right)}{f_n^2 - 4f^2} \right)^2 \sum_{n=1}^{n} \sum_{k=-1}^{n-1} 2s_n s_k \cos \left( \frac{2\pi f}{nf} \right)
\]

Liu presents a BCS sequence:

\[
(\{s_0, s_1, \ldots , s_{n-1} \}, f_c) = (\{1, -1, -1, -1, 1, 1, 1, 1, 1 \}, 1)
\]

The normalized PSD of MSK-BCS(\{1, -1, -1, -1, -1, 1, 1, 1, 1, 1 \}, 1) is shown in Fig. 1.

As we can observe, MSK-BCS signal has more power on side lobes which fade quickly. And the signal takes on constant envelope and a very good spectral confinement.

III. COMPATIBILITY ASSESSMENT METHODOLOGIES

If the interoperability signals using MSK-BCS modulation for BeiDou (BD), GPS and Galileo systems separately will be spread in C band, compatibility as the fundamental aspect in the design of any navigation signal is assigned higher priority than other performances. Therefore the compatibility in band of the signals is assessed in advance essentially.

Degradation of effective carrier-power-to-noise density ratio denoted as \( \Delta(C/N_0)_{\text{ef}} \) [6] based on Spectral Separation Coefficient (SSC) [7] and Code Tracking Spectral Sensitivity Coefficient (CTSSC) [8] are two kinds of compatibility assessment methodologies in general. The reason not to use effective carrier-power-to-noise density ratio written as \( (C/N_0)_{\text{ef}} \) is that it evaluates interference at the input for the general receiver. But \( \Delta(C/N_0)_{\text{ef}} \) which is the common quantity to assess effect of interference reflects the relative influence of the signals interfered when more than two systems are working together. Accordingly, we often don’t use \( (C/N_0)_{\text{ef}} \) to assess interference due to different threshold of acquisition, carrier tracking and data demodulation for different receiver. Yet \( \Delta(C/N_0)_{\text{ef}} \) is independent of the receiver design so that it’s more reasonable as the index to reflect interference in the case of the intersystem interference [6]. In addition, SSC [7] can be used to evaluate how overlapped PSD of two different signals at the same band. And it assesses the effects of interfering signals on the receiver prompt correlator channel processing phases including acquisition, carrier phase tracking and data demodulation. Besides, CTSSC [8] evaluates the impact of interfering signals onto the code tracking performance. Accordingly, \( \Delta(C/N_0)_{\text{ef}} \) based on SSC and CTSSC are more comprehensive and appropriate compatibility assessment methodologies. Following a detailed derivation of the methodology including equations and computation principles is provided.

A. Spectral Separation Coefficient

Based on the J. Betz’s theory, the SSC [7] is determined by considering that the Signal to Noise Interference Ratio (SNIR) at the prompt correlator output
and can be used to evaluate the effects of interfering signals for the receiver prompt correlator channel processing phases including carrier acquisition, carrier phase tracking or data demodulation. Define normalized power spectral density of the reference signal in the receiver \( G_r(f) \), the normalized power spectral density of \( j \)-th interfering signal on the \( i \)-th satellite \( G_{i,j}(f) \), and the receiver’s front end has complex bandwidth \( \beta_i \). Suppose that the front-end bandwidth is wide enough to contain substantially the desired signal power. The SSC for all signals on the assumption of ideal random codes is then [9]

\[
\kappa_{i,j}^r = \frac{\int_{-\beta_i}^{\beta_i} G_{i,j}(f) G_r(f) df}{\int_{-\beta_i}^{\beta_i} G_r(f) df}
\]

(4)

where \( \kappa_{i,j}^r \) is the SSC of the \( j \)-th interfering signal on the \( i \)-th satellite to a desired signals.

In the paper, we analyze the compatibility performance of MSK-BCS as the interoperability signals’ modulation in C band. Therefore Table 1 lists the SSC of MSK-BCS to itself. From Table 1, we can see that the SSC of between MSK-BCS and itself is -67.2531dB-Hz.

### TABLE I. SPECTRAL SEPARATION COEFFICIENT

<table>
<thead>
<tr>
<th>Case</th>
<th>SSC(dB-Hz)</th>
<th>MSK-BCS MSK-BCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-67.2531</td>
</tr>
</tbody>
</table>

B. Code Tracking Spectral Sensitivity Coefficient

Code Tracking Spectral Sensitivity Coefficient (CT_SSC) presented by F.Soualle [8] could be representative of the effects of interfering signals onto the code phase tracking. The expression of CT_SSC for a coherent Delay Lock Loop is deduced [8]

\[
\chi_{i,j}^r = \frac{\int_{-\beta_i}^{\beta_i} G_r(f) G_{i,j}(f) \sin^2(\pi f \Delta) df}{\int_{-\beta_i}^{\beta_i} G_r(f) \sin^2(\pi f \Delta) df}
\]

(5)

In the previous expression, \( \Delta \) is the early-to-late spacing of the correlator taps in seconds. \( \chi_{i,j}^r \) is the CTSSC of the \( j \)-th interfering signal on the \( i \)-th satellite to a desired signal \( s \). When comparing with the expression of the SSC, it is shown that the CT_SSC introduces in the inner product of the PSDs for the desired and interfering signals a sinus squared function which originates from the use of early-to-late spacing of the correlator [8]. The term \( \sin^2(\pi f \Delta) \) comes from the shifts of \( \pm \Delta/2 \) in the time domain those are required to generate the early and late channels and those cause a sinus function in the frequency domain. It seems that the interfering signal would be correlated with a replica based upon the distinction between the early and late replicas [8].

Table 2 summarizes the CT_SSC applied in this paper. From Table 2, one can observe that the CTSSC of between MSK-BCS modulation and itself is -62.9923dB-Hz.

### TABLE II. CODE TRACKING SPECTRAL SENSITIVITY COEFFICIENT

<table>
<thead>
<tr>
<th>Case</th>
<th>CTSSC(dB-Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSK-BCS</td>
<td>-62.9923</td>
</tr>
</tbody>
</table>

C. Equivalent Noise Power Density

When SSC or CTSSC is multiplied with the power of the interfering signal, it will lead to an equivalent white power spectral density that simply can be added to this of the thermal noise, causing an aggregate and equivalent white noise PSD. In other words, equivalent noise power density means “whiten” the power spectral density of the interfering signals [8].

Suppose the effect of filtering within the pass band and other aspects of receiver processing losses can be neglected, the calculation for the aggregate equivalent noise power density of the sum of intrasystem and inter system interference when a receiver at a given location on the earth in view at any time over a satellite period can be defined as[9]:

\[
I(t) = \sum_{i=1}^{M} \sum_{j=1}^{K_i} C_{i,j}(t) \lambda_i^s
\]

(6)

where \( \lambda_i^s \) is the SSC or CTSSC of the \( j \)-th interfering signal on the \( i \)-th satellite to a desired signal \( s \). \( M \) is the visible number of satellites, \( K_i(t) \) is the number of signals transmitted by satellite \( i \) and \( C_{i,j}(t) \) is the received power of the \( j \)-th interfering signal on the \( i \)-th satellite and it can be written as [9]

\[
C_{i,j}(t) = \frac{P_{t,i} G_i(t) G_{\text{wav}}}{L_{\text{dist}}(t) L_{\text{sm}} L_{\text{pol}}}
\]

(7)

### TABLE III. RECEIVE POWER PARAMETERS

<table>
<thead>
<tr>
<th>( P_{t,i} )</th>
<th>The transmit power of the ( j )-th signal from the ( i )-th satellite</th>
<th>34.8 dB [10]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_i(t) )</td>
<td>The satellite antenna gain between the ( i )-th satellite and the user receiver at time ( t )</td>
<td>( \text{BD GSO B1 satellite antenna gain} )</td>
</tr>
<tr>
<td>( G_{\text{wav}} )</td>
<td>The user receiver antenna gain between the user receiver and the ( i )-th satellite</td>
<td>L1 airborne patch antenna [11]</td>
</tr>
<tr>
<td>( L_{\text{dist}}(t) )</td>
<td>The free-space loss of signal due to the distance ( i )-th satellite and user at time ( t )</td>
<td>Equation (9)</td>
</tr>
<tr>
<td>( L_{\text{sm}} )</td>
<td>The loss of the signal caused by atmospheric loss</td>
<td>0.5 dB [10]</td>
</tr>
<tr>
<td>( L_{\text{pol}} )</td>
<td>The polarization mismatch loss</td>
<td>3dB [10]</td>
</tr>
</tbody>
</table>

Table 3 shows received power parameters of the interfering signals in detail. The transmitted power of the signals will have to be much stronger to spread an equivalent L-band signal for the increased signal attenuation in C band. The value of \( P_{t,i} \) is based on the
requirement that the signal should be tracked with a
\( C/N_0 \) at least 45 dB/Hz in C band [10]. \( G(t) \) is a function of off-boresight angle \( \alpha \) illustrated in Fig. 2.

Define the earth radius \( R_e \), the satellite elevation angle \( \varepsilon_l \) and the satellite semi-major axis \( R_{sv} \) at the user receiver, the off-boresight angle \( \alpha \) can be defined as [9]

\[
\alpha = \sin^{-1}\left( \frac{R_e \sin(\varepsilon_l + 90)}{R_{sv}} \right) \tag{8}
\]

Fig. 3 describes user receiver antenna gain. Suppose the satellite systems for BeiDou, GPS and Galileo use typical profile of BD Geo-Stationary Earth Orbit (GSO) B1 satellite antenna gain provided in the Fig. 4.

Define the speed of light \( c \), the distance of user and satellite at time \( t \), and centre frequency of the signal \( f \) assumed to be 5019.86MHz [10] in C Band, \( L_{d\alpha}(t) \) is then [9]

\[
L_{d\alpha}(t) = \left( \frac{c}{4\pi d(t)f} \right)^2 \tag{9}
\]

When more than two systems are operating together in the same band, the aggregate equivalent noise power density denoted as \( I \) that is the sum of two components

\[
I = I_{\text{Inter}} + I_{\text{Intra}} \tag{10}
\]

where \( I_{\text{Inter}} \) is the equivalent noise power density of inter-system interference. \( I_{\text{Intra}} \) is the aggregate equivalent noise power density of intra-system interference.

Suppose the interoperability signals modulated by MSK-BCS modulation separately will be spread over satellites of constellation of BeiDou (BD), GPS and Galileo in C band. When GPS and BeiDou are operating together, regarding BeiDou MSK-BCS on \( i \)-th satellite as the desired satellite, \( I_{\text{Inter}} \) and \( I_{\text{Intra}} \) can be denoted as

\[
\begin{align*}
I_{\text{Inter}} &= I_{\text{GPS, MSKBCS}} \\
I_{\text{Intra}} &= I_{\text{BD, others, MSKBCS}}
\end{align*} \tag{11}
\]

where \( I_{\text{GPS, MSKBCS}} \) stands for the equivalent noise power density of GPS MSK-BCS of satellites of GPS constellation. And \( I_{\text{BD, others, MSKBCS}} \) is the equivalent noise power density of BeiDou MSK-BCS from the other satellites of the same constellation.

D. Degradation of Effective Carrier-power-to-noise Density Ratio

When without consideration external interference, \( \Delta(C/N_0)_{\text{eff}} \) is written as [9]

\[
\Delta(C/N_0)_{\text{eff}} = \frac{C}{N_0 + I_{\text{Intra}}} \frac{1 + \frac{I_{\text{Inter}}}{N_0 + I_{\text{Intra}}}}{\frac{N_0 + I_{\text{Intra}}}{N_0 + I_{\text{Inter}}}} \tag{12}
\]

Transform formula above into dB form as

\[
\phi_{\text{Inter}} = 10 \cdot \log \left( 1 + \frac{I_{\text{Inter}}}{N_0 + I_{\text{Intra}}} \right) \tag{13}
\]

Define the PSD of the thermal noise \( N_0 \) is -204dBW/Hz for high-end user receiver.

IV. SIMULATIONS

This section provides the parameters of space constellations of BD, GPS and Galileo, simulation parameters, simulation scenarios and results.

A. Space Constellations and Simulation Parameters

Due to the space constellations for C band have not be set, suppose the space constellations of BeiDou, GPS and Galileo systems still use those of L band and the corresponding parameters [9] are shown in Table 4. The simulation results are obtained considering the following simulation parameters:
• Simulation Time Period: each constellation propagated 10 days
• Time Step: 10 minutes
• Grid Resolution: 5° × 5° grid for the user locations has been used
• Elevation Angle: 5°
• Front End Bandwidth of the receiver: 24 MHz
• Early-to-Late Spacing: one code chip duration

TABLE IV. SPACE CONSTELLATION AND SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BeiDou</th>
<th>Galileo</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constellation</td>
<td>SGSO:</td>
<td>Walker27/3/1</td>
<td>3/6 Plus</td>
</tr>
<tr>
<td></td>
<td>58.75°</td>
<td>27/3/1</td>
<td>1 active</td>
</tr>
<tr>
<td></td>
<td>IGSO:</td>
<td>56</td>
<td>0</td>
</tr>
<tr>
<td>Inclination(*)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Semi-major Axis (km)</td>
<td>42164.2</td>
<td>29601.297</td>
<td>26559.7</td>
</tr>
</tbody>
</table>

B. Simulation Scenarios and Results

In the paper, suppose C band will spread interoperability signals modulated by MSK-BCS([1, 1, 1, 1, 1, 1, 1, 1, 1]) for BeiDou, GPS, and Galileo systems respectively. The signals are denoted as BeiDou MSK-BCS, GPS MSK-BCS, and Galileo MSK-BCS in the C band. Following, the simulation scenarios and results for radio frequency compatibility of BeiDou, GPS, and Galileo systems are provided.

All the interference simulations base on the worst scenarios with maximum emission power for all interfering signals, minimum emission power for the desired signal, and maximum Δ(C/N0)eff of interference over all time steps [12].

The six simulation scenarios include:

Scenario 1: BeiDou MSK-BCS → Galileo MSK-BCS
(Space Constellation is interfered by BeiDou MSK-BCS)

Scenario 2: BeiDou MSK-BCS → Galileo MSK-BCS
(BeiDou MSK-BCS signal is interfered by Galileo MSK-BCS)

Scenario 3: BeiDou MSK-BCS → GPS MSK-BCS
(GPS MSK-BCS signal is interfered by BeiDou MSK-BCS)

Scenario 4: BeiDou MSK-BCS → GPS MSK-BCS
(BeiDou MSK-BCS signal is interfered by GPS MSK-BCS)

Scenario 5: Galileo MSK-BCS → GPS MSK-BCS
(Galileo MSK-BCS signal is interfered by GPS MSK-BCS)

Scenario 6: Galileo MSK-BCS → GPS MSK-BCS
(GPS MSK-BCS signal is interfered by Galileo MSK-BCS)

When the compatibility assessment methodology uses degradation of effective carrier-power-to-noise density ratio based on Spectral Separation Coefficient denoted as Δ(C/N0)eff.ssc, the simulation results are shown in Fig. 5, Fig. 6 and Fig. 7.

And when the compatibility assessment methodology uses degradation of effective carrier-power-to-noise density ratio based on Code Tracking Spectral Sensitivity Coefficient, the simulation results are shown in Fig. 8, Fig. 9 and Fig. 10.

The maximum Δ(C/N0)eff based on SSC and CTSSC are summarized in the following Table 5.

As can be seen from Table 5, when the interoperability signals for BeiDou, GPS and Galileo systems are modulated by MSK-BCS respectively, and when BeiDou signals are interfered by Galileo signals, all the maximal values of degradation of effective carrier-power-to-noise density ratio based on Spectral Separation Coefficient and Code Tracking Spectral Sensitivity Coefficient are about 2.5853dB, 3.6369dB separately. Conversely, when Galileo signals are interfered by BeiDou signals, the maximal values of Δ(C/N0)eff.ssc and Δ(C/N0)eff.ctssc are approximate 1.5303dB, 2.0164dB respectively. Similarly the maximal values of Δ(C/N0)eff.ssc and Δ(C/N0)eff.ctssc are 3.3551dB, 4.6028dB when BeiDou signals are interfered by GPS signals. On the contrary the values of GPS as desired and Galileo as interfering signal are 1.4445dB, 1.8702dB. In the same way, the maximal values of Δ(C/N0)eff.ssc and Δ(C/N0)eff.ctssc for Galileo signals interfered by GPS are about 2.7225dB, 3.4649dB. The results are whereas 1.8858dB, 2.4132dB. Obviously, as can be seen from Table V, the maximal values of Δ(C/N0)eff.ctssc are much higher than the maximal values of Δ(C/N0)eff.ssc. This is because the CT.SSC is higher than the SSC of the pair of MSKBCS, resulting in the higher Iinter in the intersystem interference computation.

TABLE V. MAXIMUM Δ(C/N0)eff

<table>
<thead>
<tr>
<th>Case</th>
<th>Max Δ(C/N0)eff.ssc (dB)</th>
<th>Max Δ(C/N0)eff.ctssc (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeiDou MSK-BCS → Galileo MSK-BCS</td>
<td>1.5303</td>
<td>2.0164</td>
</tr>
<tr>
<td>BeiDou MSK-BCS → GPS MSK-BCS</td>
<td>2.5853</td>
<td>3.6369</td>
</tr>
<tr>
<td>BeiDou MSK-BCS → GPS MSK-BCS</td>
<td>1.4445</td>
<td>1.8702</td>
</tr>
<tr>
<td>BeiDou MSK-BCS → GPS MSK-BCS</td>
<td>3.3551</td>
<td>4.6028</td>
</tr>
<tr>
<td>Galileo MSK-BCS → GPS MSK-BCS</td>
<td>1.8858</td>
<td>2.4132</td>
</tr>
<tr>
<td>Galileo MSK-BCS → GPS MSK-BCS</td>
<td>2.7225</td>
<td>3.4649</td>
</tr>
</tbody>
</table>

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Figure 5. Interference between BeiDou MSK-BCS and Galileo MSK-BCS

Figure 6. Interference between BeiDou MSK-BCS and GPS MSK-BCS

Figure 7. Interference between Galileo MSK-BCS and GPS MSK-BCS

Figure 8. Interference between BeiDou MSK-BCS and Galileo MSK-BCS
Moreover, by reference [13] it can be seen when the signals are modulated by Multilevel Binary Coded Symbols (MBOC), the intersystem interference is higher than those of modulated by proposed MSK-BCS. That is to say the proposed MSK-BCS is better than MBOC as the interoperability signals modulation in C band.

With the results from the above simulation results, it is clear that the BeiDou system leads to intersystem interference on Galileo and GPS and that the maximal values are lower than those of Galileo and GPS interfering on BeiDou.

V. CONCLUSIONS

In the paper, the interoperability signal modulated by MSK-BCS([1,1,1,1,1,1,1,1,1,1]) for BeiDou, GPS and Galileo systems with constellations configuration just as L band in only 20MHz narrow bandwidth of C band is supposed, and the intersystem interference is analyzed. The compatibility assessment methods by using degradation of effective carrier-power-to-noise density ratio based on Spectral Separation Coefficient and Code Tracking Spectral Sensitivity Coefficient are utilized. Simulation results reveal the interference for the receiver prompt correlator channel processing and code phase tracking induced by navigation satellite system to each other and indicate the interference for code tracking is more than that for prompt correlator channel processing. In addition, the interference to GPS and Galileo induced by BeiDou is minimum.

In a word, the paper would be of some great importance for the signal design in C band.

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REFERENCES


