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REVIEW PAPER

Assessing Radio Frequency Compatibility Between Galileo and Compass

Wei Liu[*], Yuan Hu[#], Xingqun Zhan[†], and Chuanrun Zhai[†]

[*]Shanghai Maritime University, Shanghai, 200135, China
[#]Shanghai Ocean University, Shanghai, 201306, China
[†]Shanghai Jiao Tong University, Shanghai, 200240, China
[*]Email: liu@sjtu.org

ABSTRACTS

The radio frequency compatibility between Galileo and Compass has become a matter of great concern for the system providers and user community. This paper mainly deals with the intersystem interference between Galileo and Compass systems and displays some important analysis results. First, a comprehensive methodology for the radio frequency compatibility assessment is described, considering the geometry-dependent and time-varying terms such as space constellation, signal modulation, emission power level, space loss, satellite antenna gain, and user receiver characteristic. Second, real simulations were carried out to assess the interference effects where Galileo and Compass signals were sharing the same band. Simulation results show that Compass introduces intersystem interference to Galileo, but the interference effects are lower than those of Compass interfered to Galileo signals. In addition, the radio frequency compatibility in Asia-Pacific region was analysed. It was found that the maximum interference suffered by Galileo from Compass was below 0.25dB under existing rules of coordination at International Telecommunication Union (ITU). In other words, Compass can provide a sound basis for compatibility with Galileo.

Keywords: Signal compatibility, interference assessment, navigation systems, spectral separation coefficient

1. INTRODUCTION

With the development of global navigation satellite systems (GNSS), user community will benefit from the multiple GNSS constellations which will result in improved observed geometry, increasing end-user accuracy everywhere and improving service availability in environments where satellite visibility is often obscured. Meanwhile, multiple constellations broadcasting more signals in the same frequency bands will cause interference effects among the systems, known as GNSS radio frequency compatibility[1-4].

Since the very moment Galileo was planned, the interoperability and compatibility have been the hot topics. Interoperability refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system. Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and/or other harm to an individual system and/or service[5,6]. To make open signals and services interoperable and maximise benefit to GNSS users, GNSS signals and services needs to be compatible.

Nowadays, many countries are developing their own GNSS or space-based augmentation systems (SBAS). In 1998, the European Union decided to pursue its own GNSS, known as Galileo, which is still in its development phase. On 26 May 2003, the first stage of the Galileo Programme was agreed upon officially by the European Union and the European Space Agency[7]. In April 2007, China launched the first middle-earth orbit (MEO) satellite for Compass, which the nation plans to turn into a full-fledged GNSS system within a few years. In April 2009, a second Compass satellite–this one a geostationary spacecraft–was launched, which marks the return of China to its GNSS Launch Programme two years after the initial venture into space. The country will complete a 30+ satellite Compass constellation by 2015[8-10]. Using signal structures similar to other GNSS systems and sharing frequencies near to or overlapping those of Galileo, the Galileo and Compass signals overlay becomes a matter of great concern for the system providers and user community. This issue continues to be unresolved after two meetings between Chinese and European Union representatives. This paper mainly deals with the interference computation and simulation between the above-mentioned systems and displays some important analysis results.

Three different approaches (field testing, computer simulation approach, and analytical approach) have been developed to assess the intra-system interference and intersystem interference. Field testing requires measurements using actual scenario, and it cannot be conducted during the system development. Computer simulation approach can provide realistic results, but it is time-consuming to perform the simulation for every interference scenario[11,12]. Analytical approach provides a useful tool for interference effects assessment without resorting to the use of constellation simulation for every simulation scenario[13]. Although computer simulation is more time-consuming, it can provide more realistic results.

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In this paper the computer simulation approach has been taken into account in the interference computation for pursuing more realistic results. A comprehensive methodology is presented which accounts for the space constellation, signal modulation, emission power level, space loss, satellites antenna gain, and user receiver characteristic.

Considering that a lot of attention was paid to the signal spectrum overlaps at E1/B1 and E6/B3 bands between these systems, intersystem interference was computed mainly on these bands where Galileo and Compass signals were sharing the same band. All satellite signals which were taken into account in the simulations, included: (i) the Galileo E1 PRS, E1 OS, E6 CS, and E6 PRS signals, and (ii) the Compass B1, B1-2, and B3 signals. In addition, several worse scenarios were simulated, using 5°×5° grid for longitude and latitude and sampling the period time by small time steps, i.e. 60 s.

2. METHODOLOGY

2.1 Simulation Formulae

To provide a general quantity to reflect interference effects on characteristics at the input of the non-specific receiver, a quantity called effective carrier power-to-noise density C/N_0, denoted as $(C/N_0)_{eff}$, was introduced byBetz[14]. When there is noise and one non-white interference signal, the effect of filtering can be neglected within the passband, the effective C/N_0 can be written as

$$\left(\frac{C}{N_0}\right)_{eff} = \frac{C\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df}{N_0\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df + C_l\int_{-\beta_r/2}^{\beta_r/2} G_s(f)G_l(f)df} \tag{1}$$

where $G_s(f)$ is the normalised power spectral density of the desired signal. C is the received power of the useful signal. N_0 is the power spectral density of the thermal noise. It was assumed that N_0 to be –201.5 dB W/Hz. $G_1(f)$ is the normalised spectral density of the interfering signal. C_1 is the received power of the interfering signal. b_r is the receiver front-end bandwidth. To avoid a significant amount of computer time, this paper has assumed the ideal random codes for the interference simulations.

The $(C/N_0)_{eff}$ can be interpreted as the carrier power-to-noise density ratio caused by an equivalent white noise that would yield the same correlation output variance obtained in the presence of interference signal. When there are intra-system and intersystem interferences coexisting, the $(C/N_0)_{eff}$ can be expressed as

$$(C/N_0)_{eff} = \frac{C\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df}{N_0\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df + \sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\int_{-\beta_r/2}^{\beta_r/2} G_s(f)G_{i,j}(f)df}$$

$$= \frac{C}{N_0 + \sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\frac{\int_{-\beta_r/2}^{\beta_r/2} G_s(f)G_{i,j}(f)df}{\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df}}$$

$$= \frac{C}{N_0 + I_{GNSS}} \tag{2}$$

where

$$I_{GNSS} = \sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\frac{\int_{-\beta_r/2}^{\beta_r/2} G_s(f)G_{i,j}(f)df}{\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df} \tag{3}$$

I_{GNSS} is the aggregate equivalent noise power density of the combination of intra-system and intersystem interferences. M is the visible number of satellites. K_i is the number of signals transmitted by satellite i. $C_{i,j}$ is the received power of the j^{th} interfering signal on the i^{th} satellite.

From Eqn (2) it is clear that the impact of the interference onto $(C/N_0)_{eff}$ is directly related to the spectral separation coefficient (SSC) of the j^{th} interfering signal on the i^{th} satellite to a desired signal s, and the SSC is defined[15] as

$$\kappa_{i,j}^{s} = \int_{-\beta_r/2}^{\beta_r/2} G_s(f)G_{i,j}(f)df \tag{4}$$

When more than two systems are operating together, the aggregate equivalent noise power density I_{GNSS} is the sum of two components

$$I_{GNSS} = I_{Intra} + I_{Inter} \tag{5}$$

where I_{Intra} is the equivalent noise power density of interfering signals from satellites belonging to the same system as the desired signal, and I_{Inter} is the aggregate equivalent noise power density of interfering signals from satellites belonging to the other systems.

A general way to calculate $(C/N_0)_{eff}$ has been introduced by interfering signals from satellites belonging to the same system or other systems is based on Eqn (2). Besides calculating the $(C/N_0)_{eff}$, the calculation of effective C/N_0 degradation is more interesting when more than two systems are operating together. The degradation of effective C/N_0 in the case of the intersystem interference[16] is

$$\Delta(C/N_0)_{eff} = \frac{\dfrac{C}{N_0 + I_{Intra}}}{\dfrac{C}{N_0 + I_{Intra} + I_{Inter}}} = 1 + \frac{I_{Inter}}{N_0 + I_{Intra}} \tag{6}$$

Therefore, the expression of intersystem interference in dB is as

$$\phi_{Inter} = 10\cdot\log\left(1 + \frac{I_{Inter}}{N_0 + I_{Intra}}\right) \tag{7}$$

For example, if Galileo and Compass are operating together, regarding Galileo E1 OS signal on i^{th} satellite as the desired satellite and the desired signal, I_{Intra} and I_{Inter} can be expressed as

$$I_{Intra} = I_{E1OS,others} + I_{PRS} \tag{8}$$

$$I_{Inter} = I_{Compass} = I_{B1} + I_{B1-2} \tag{9}$$

where $I_{E1OS,others}$ is the equivalent noise power density of Galileo E1 OS signal belonging to the other satellites of the Galileo constellation.

2.2 Equivalent Noise Power Density

Using Eqn (4), the equivalent noise power density (I_{Intra} or I_{Inter}) can be simplified as

$$I_x = \frac{\sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\kappa_{i,j}^{s}}{\int_{-\beta_r/2}^{\beta_r/2} G_s(f)df} = \frac{1}{\lambda^s}\sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\kappa_{i,j}^{s} \tag{10}$$

where

$$\lambda^s = \int_{-\beta_r/2}^{\beta_r/2} G_s(f)df \tag{11}$$

When the front-end bandwidth is wide enough to contain essentially the desired signal power, Eqn (10) becomes

$$I_x = \sum_{i=1}^{M}\sum_{j=1}^{K_i} C_{i,j}\kappa_{i,j}^{s}, \quad \lambda^s = 1 \tag{12}$$

The user received power $C_{i,j}$ of the j^{th} signal belonging to the i^{th} satellite can be written in terms of satellite transmit power, satellite and user receiver antenna gains, space loss and polarisation loss[17] as

$$C_{i,j} = \frac{P_{i,j}G_i G_{user}}{L_{dist}L_{atm}L_{pol}} \tag{13}$$

where $P_{i,j}$ is the transmit power of the j-th signal belonging to the i-th satellite, L_{dist} is the loss of signal due to distance i-th satellite and user, L_{atm} is the loss of the signal due to atmospheric loss, L_{pol} is the polarisation mismatch loss, G_i is the satellite antenna gain between the i-th satellite to the user receiver, and G_{user} is the user receiver antenna gain between the user receiver and the i-th satellite.

The atmospheric loss L_{atm} was estimated to be 0.5 dB for all systems[17]. This value is usually used in the GNSS radio frequency coordination. However, it should be noted that the atmospheric loss will impact by fading, especially during varying weather conditions. The polarisation mismatch loss is assumed to be 1.0 dB and 1.5 dB for Galileo and Compass user receiver antennas, respectively. The satellite antenna gain G_i is a function of the off-boresight angle[18] α, it has been be illustrated in Fig. 1.

It must be noted that different signals from Galileo and Compass have different satellite antenna gain profiles. Typical profile of GPS Block IIA satellite antenna gain is depicted in Fig. 2.

The signal distance loss L_{dist} can be expressed as

$$L_{dist} = \left(\frac{c}{4\pi d f_0}\right)^2 \tag{14}$$

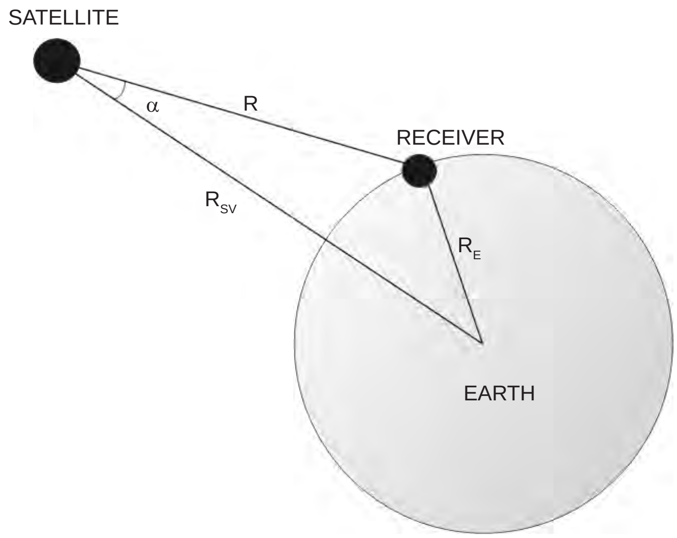

Figure 1. Illustration of off-boresight angle.

where c is the speed of light, d is the distance of satellite the and user, f_0 is the signal centre frequency.

For the aggregate equivalent noise power density calculation, the constellation configuration, satellite and user receiver antenna gain patterns, and the space loss have been included in the link equation. User receiver location must be taken into account for measuring the interference effects. When a receiver is at a given location m on the earth at any time over a 24 h period, the aggregate equivalent noise power density to a desired signal s can be written as follows:

$$I_m^s(t) = \frac{1}{\lambda^s}\sum_{i=1}^{M(t)}\sum_{j=1}^{K_i} \frac{P_{i,j}G_i(t)G_{user}(t)}{L_{dist}(t)L_{atm}L_{pol}}\kappa_{i,j}^{s} \tag{15}$$

Equation (15) is the sum of all equivalent noise power density from all signals of all satellites in view at any time. When the desired satellite is used, it must subtract the power spectral density of the desired signal from the desired satellite.

3. SIMULATION PARAMETERS

3.1 Space Constellations

The space constellation parameters[19-21] of Galileo and Compass are summarised in Table 1. The reference Galileo

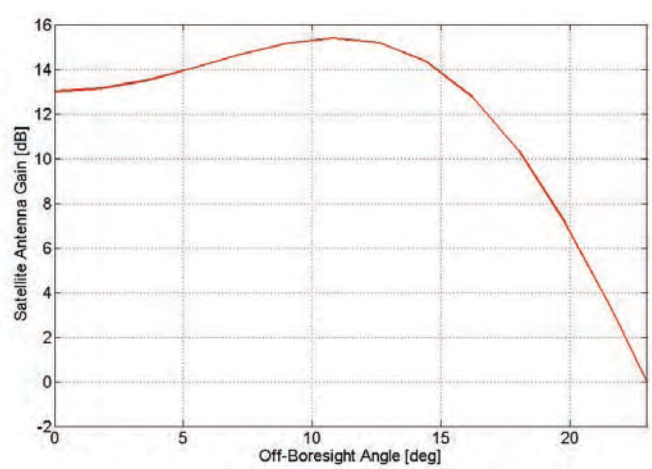

Figure 2. Typical profile of GPS block IIA satellite antenna gain.

will consists of 30 satellites in three orbit planes, with 27 operational spacecraft and three in-orbit spares (1/plane). According to European Space Agency[19], the Compass will consist of 27 MEO satellites, 5 GEO and 3 IGSO satellites. As the Galileo and Compass are under constructing, ideal constellation parameters are taken from Table 1. The Galileo and Compass space constellations are shown in Fig. 3.

Table 1. Space constellation parameters

Parameter	Galileo	Compass
Constellation	Walker 27/3/1	5GSO+30NGSO 5GEO: 58.75°,80°,110.5°,140° and 160° E 3IGSO 27 MEO:Walker27/3/1
Inclination (°)	56	55
Eccentricity	0	IGSO: 0 MEO: 0
Semi-major axis(km)	29601.297	IGSO: 42164.2 MEO: 27878

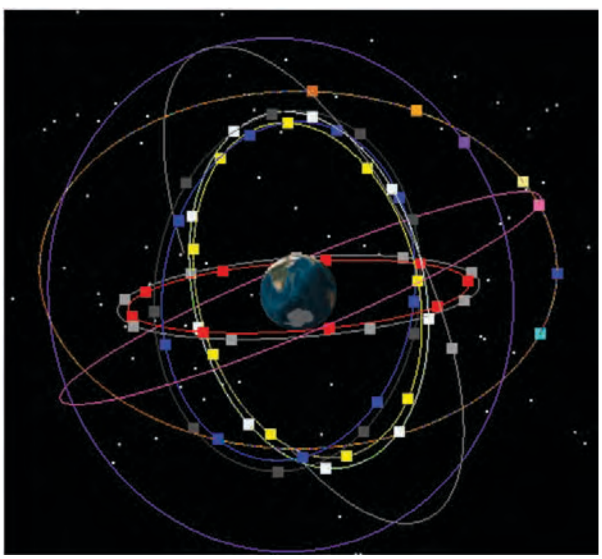

Figure 3. Galileo and Compass space constellations.

3.2 Signal Parameters

The frequency bands for Galileo and Compass are shown in Fig. 4. As it can be seen, a lot of attention has to be paid to the signals spectrum overlaps at E1/B1 and E6/B3 bands between two systems. Thus, we will concentrate only the interference simulation on the E1/B1 and E6/B3 bands in this paper.

The Table 2 gives an overview of the technical characteristics of Galileo and Compass signals in E1/B1 and E6/B3 bands[22,23]. The detailed information about the signal parameters can be found in the Galileo Interface Control Document (ICD) and International Telecommunication Union (ITU) related documents[19, 20].

The power spectral densities (PSDs) of the Galileo and Compass signals in E1/B1 and E6/B3 bands are shown in Figs 5 and 6, respectively. As shown, due to the frequency

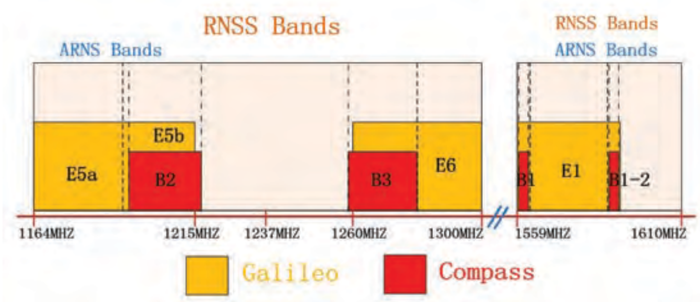

Figure 4. Galileo and Compass frequency bands.

Table 2. Galileo and Compass signal parameters in E1/B1 and E6/B3 bands

System name	Service type	Carrier frequency (MHz)	Modulation type	Chip rate (Mcps)
Galileo	E1 OS	1575.42	MBOC (6,1,1/11)	1.023
	E1PRS	1575.42	BOCc (15,2.5)	2.5575
	E6 CS	1278.75	BPSK(5)	5.115
	E6PRS	1278.75	BOCc(10,5)	5.115
Compass	B1	1561.098	QPSK	2.046
	B1-2	1589.742	QPSK	2.046
	B3	1268.52	QPSK	10.23

bands overlap, the signals of Galileo or Compass may pose a source of interference and degrade the performance of each other. Therefore, the intersystem interference will be carefully computed and analysed on these bands where Galileo and Compass signals are sharing the same band.

4. SIMULATION RESULTS

According to Eqn (2), it can be seen that $(C/N_0)_{eff}$ is directly related to the spectral separation coefficient (SSC) between the desired and interfering signals. In Table 3 several SSCs for different civil signals in E1/B1 and E6/B3 bands are calculated using Eqn (4). The power spectral densities are normalised to the transmission bandwidth of 40.92 MHz. In addition, the user receiver bandwidth of 40.92 MHz is assumed. Obviously, Compass has good spectral separation with Galileo. For example, the spectral overlapping of the Compass B1-I with the Galileo E1 OS signal is approximately 22.86 dB better than that of Galileo L1 OS signal self SSC. Table 3 also shows Compass B3-I signal has good spectral separation with Galileo E6 CS signal.

All simulation results refer to the worse case scenarios. The worse case scenarios are assumed that minimum emission power for desired signal, maximum emission powers for all interfered signals, and maximum $(C/N_0)_{eff}$ degradations over all simulation time steps. In this paper, the ideal environmental

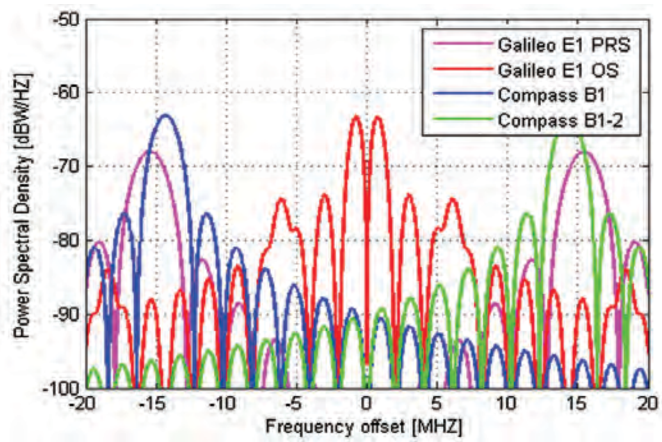

Figure 5. PSDs of the Galileo and compass signals in E1/B1 band.

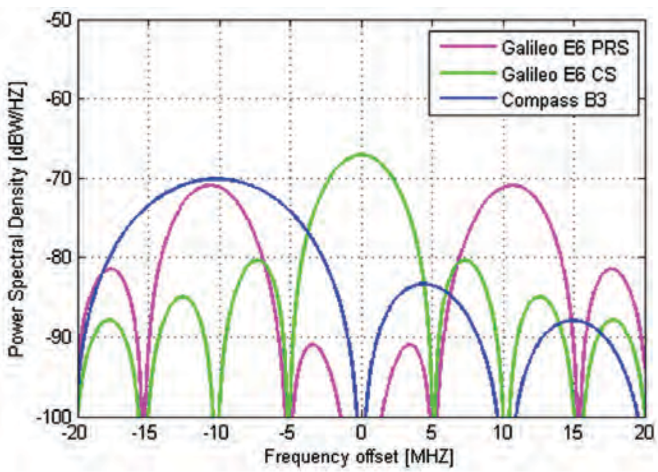

Figure 6. PSDs of the Galileo and compass signals in E6/B3 band.

Table 3. Spectral separation coefficients in E1/B1 and E6/B3 bands

SSC [dB-Hz]		Galileo		Compass		
		E1 OS	E6 CS	B1-I	B1-2-I	B3-I
Tx BW[MHz]		40.92	40.92	40.92	40.92	40.92
Rx BW[MHz]		40.92	40.92	40.92	40.92	40.92
Galileo	E1 OS	-65.46	-	-88.32	-88.32	-
	E6 CS	-	-68.63	-	-	-82.73
Compass	B1-I	-88.32	-	-64.78	-98.80	-
	B1-2-I	-88.32	-	-98.80	-64.78	-
	B3-I	-	-82.73	-	-	-71.43

conditions and worse case scenarios are considered in the simulations. The external non-GNSS interference sources and the impact of urban landscapes on interference will be neglected in the simulations. However, the impact of different environmental conditions must be considered in realistic simulations. In this paper, only the results of the worse scenarios have been shown where Galileo and Compass are sharing the same band. The worse scenarios include:

Scenario 1 Galileo E1 OS ← Compass B1 and B 1-2

When Galileo E1 OS civil signal is interfered by Compass B1 and B1-2 signals, the I_{Intra} and I_{Inter} can be expressed as

$$\left.\begin{aligned} I_{Intra} &= I_{E1OS,others} + I_{PRS} \\ I_{Inter} &= I_{B1-I} + I_{B1-Q} + I_{B1-2-I} + I_{B1-2-Q} \end{aligned}\right\} \quad (16)$$

Scenario 2 Compass B1-I ← Galileo E1 OS and E1 PRS

When Compass B1-I civil signal is interfered by Galileo E1 OS and E1 PRS signals, the I_{Intra} and I_{Inter} can be written as

$$\left.\begin{aligned} I_{Intra} &= I_{B1-I,others} + I_{B1-Q} + I_{B1-2-I} + I_{B1-2-Q} \\ I_{Inter} &= I_{E1OS} + I_{E1PRS} \end{aligned}\right\} \quad (17)$$

Scenario 3 Compass B1-2-I ← Galileo E1 OS and E1 PRS

When Compass B1-2-I civil signal is interfered by Galileo E1 OS and E1 PRS signals, the I_{Intra} and I_{Inter} can be rewritten as

$$\left.\begin{aligned} I_{Intra} &= I_{B1-2-I,others} + I_{B1-2-Q} + I_{B1-I} + I_{B1-Q} \\ I_{Inter} &= I_{E1OS} + I_{E1PRS} \end{aligned}\right\} \quad (18)$$

Scenario 4 Galileo E6 CS ← Compass B3

When Galileo E6 commercial service (CS) signal is interfered by Compass B3 signal, the I_{Intra} and I_{Inter} can be expressed as

$$\left.\begin{aligned} I_{Intra} &= I_{E6CS,others} \\ I_{Inter} &= I_{B3-I} + I_{B3-Q} \end{aligned}\right\} \quad (19)$$

Note that only the interference results have been shownfor all civil signals. Due to Compass B3 signal belongs to authorised signal, the result of Compass B3 signal interfered by Galileo is not displayed in this paper.

Table 4 summarises the simulation parameters which are simulated for the effective C/N_0 degradations of all civil signals.

4.1 Galileo and Compass Intersystem Interference on E1/B1 Band

Figure 7 shows the maximum C/N_0 degradation of Galileo signal due to Compass on E1/B1 band (Scenario 1). As shown, the maximum C/N_0 degradation of Galileo E1 OS signal is raised from 0.0097 dB to 0.0169 dB.

Table 4. Simulation parameters and their values

Parameter	Value
Time period	1 day
Time step	60 s
Grid resolution	5°×5°
Elevation angle	5°
Emission bandwidth	Galileo: 40.92MHz Compass: 40.92MHz
Front-end bandwidth	40.92MHz

The maximum C/N_0 degradations of Compass B1-I and B1-2-I signals interfered by all Galileo signals in E1/B1 band (Scenario 2 and Scenario 3) are also show in Figs 8 and 9. One can obtain the maximal value of 0.2865 dB and 0.2874 dB for Compass B1-I and B1-2-I signals, respectively. Figures 7-9 show that the maximal values of Galileo interfered by Compass are lower than those of Compass interfered by Galileo on E1/B1 band. All the results show that the introduction of the Compass system leads to intersystem interference on Galileo civil signals, but the value is very small. It is also shown that Galileo suffers the maximum interference induced by Compass on E1/B1 band is below 0.25 dB using existing rules of coordination at ITU.

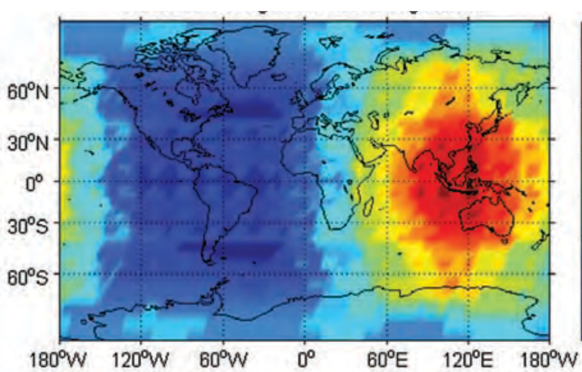

Figure 7. Maximum C/N_0 Degradation of Galileo E1 OS signal due to compass on E1/B1band.

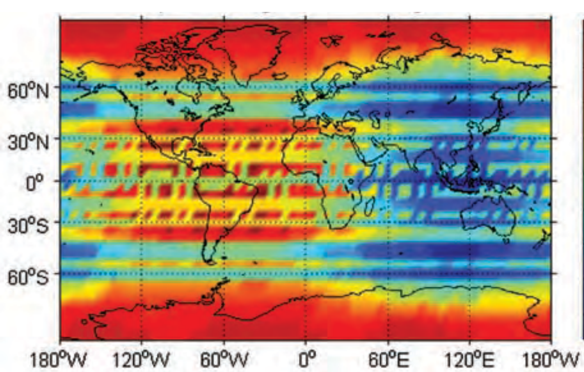

Figure 8. Maximum C/N_0 degradation of compass B1-I signal due to Galileo on E1/B1 band.

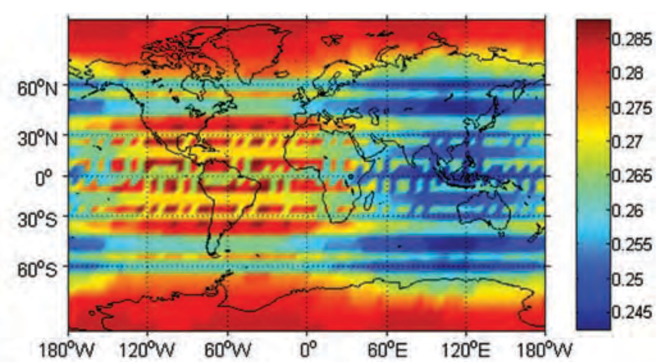

Figure 9. Maximum C/N_0 degradation of compass B1-2-I signal due to Galileo on E1/B1 band.

4.2 Galileo and Compass Intersystem Interference on E6/B3 Band

Figure 10 shows the maximum C/N_0 degradation of Galileo signal due to Compass on E6/B3 band (Scenario 4). As shown, Galileo E6 CS signal effective C/N_0 degradation is approximately 0.0166 dB higher than that of Galileo E1 OS signal. Again, the maximal value of effective C/N_0 degradation for Galileo E6 CS signal is below 0.25 dB using existing rules of coordination at ITU.

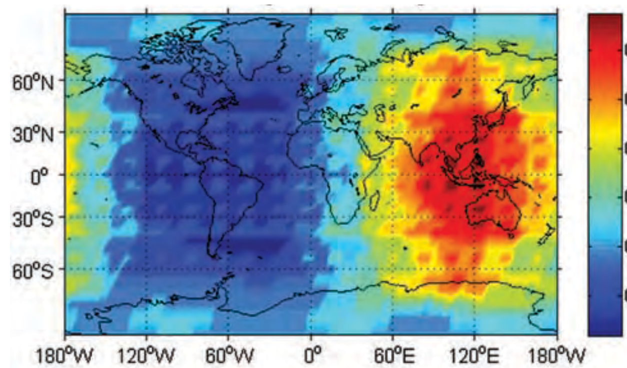

Figure 10. Maximum C/N_0 degradation of Galileo E6 CS signal due to compass on E6/B3band.

4.3 Radio Frequency Compatibility in Asia-Pacific Region

As already mentioned, Compass will consist of 27 MEO satellites, 5 GEO and 3 IGSO satellites. The rising number of Compass GEO and IGSO satellites and signals will provide more observations and improve position accuracy in the Asia-Pacific region. Meanwhile, more signals in the same frequency bands will cause more interference in this area. Thus the radio frequency compatibility between Galileo and Compass in the Asia-Pacific region need to be analysed. The simulation analysis takes 24 h simulations in the Asia-Pacific region. The Asia-Pacific region has longitude set from 55°E to 180°E, and latitude set from 60°S to 60°N. This area mainly refers to East Asia and South-east Asia, but also include Oceania countries.

Figures 11-14 illustrate the simulation results of the intersystem interference for the Galileo and Compass signals in the Asia-Pacific region. As shown in Figs 11 and 14, the maximum C/N_0 degradations of Galileo E1 OS and E 6 CS signals in the Asia-Pacific region are close to the global maximal value. This seems to be attributed to the fact that the more Compass GEO and IGSO satellites and signals cause more interference in this area. Figures 12 and 13 show that the maximum degradations of Compass B1-I and B1-2-I signals in the Asia-Pacific region are lower than those in the other regions.

Table 5 summarises the maximum C/N_0 degradations of Galileo and Compass signals at major cities in the Asia-Pacific region. Note that the cities that are closer to the equator would obtain more Compass satellites. However, the more satellites and signals will cause more interference. As shown in Table 5, The Galileo E1 OS and E6 CS user receivers at Singapore and Bangkok will suffer more interference from Compass. On the contrary, Sydney, which is located in a medium latitude region in the Southern Hemisphere, has lower interference. It

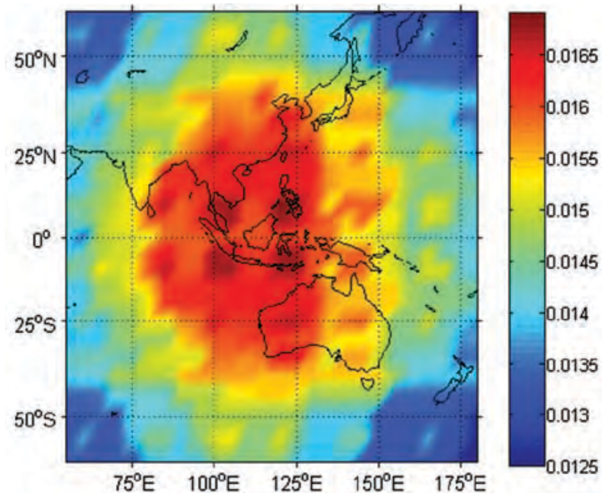

Figure 11. Maximum C/N_0 degradation of Galileo E1 OS signal due to compass on E1/B1band (regional scale).

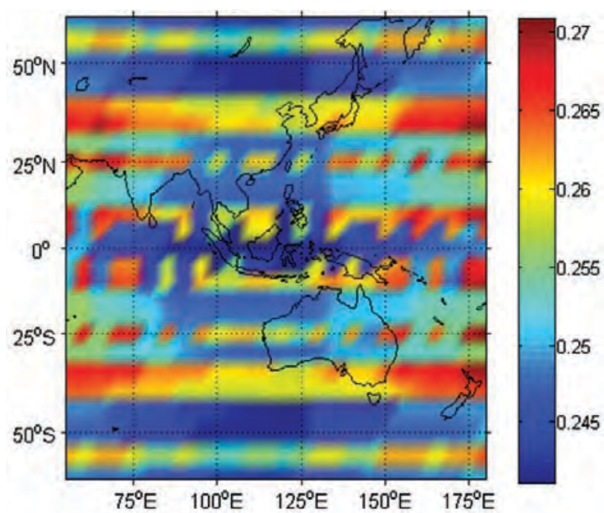

Figure 12. Maximum C/N_0 degradation of compass B1-I signal due to Galileo on E1/B1 band (regional scale).

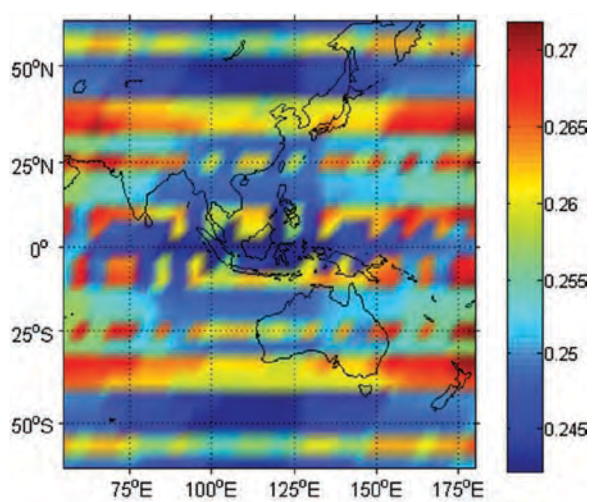

Figure 13. Maximum C/N_0 degradation of compass B1-2-I signal due to Galileo on E1/B1 band (regional scale).

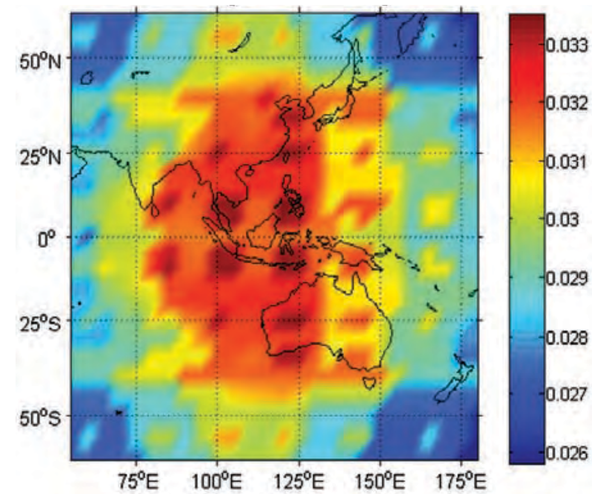

Figure 14. Maximum C/N_0 degradation of Galileo E6 CS signal due to compass on E6/B3 band (Regional scale).

Table 5. Radio frequency compatibility at major cities in the Asia-Pacific region

C/N_0 degradation (dB)	Galileo		Compass	
	E1 OS	E6 CS	B1-I	B1-2-I
Global Max.	0.0169	0.0335	0.2865	0.2874
Global Min.	0.0097	0.0204	0.2412	0.2422
Beijing	0.0161	0.0328	0.2564	0.2574
Seoul	0.0155	0.0317	0.2586	0.2596
Tokyo	0.0156	0.0318	0.2610	0.2620
Shanghai	0.0161	0.0320	0.2470	0.2480
Taipei	0.0161	0.0321	0.2606	0.2616
Hongkong	0.0163	0.0322	0.2477	0.2487
Bangkok	0.0167	0.0332	0.2583	0.2593
Singapore	0.0167	0.0333	0.2413	0.2423
Sydney	0.0150	0.0303	0.2639	0.2649

also shows that the intersystem interferences of the Compass B1-I and B1-2-I signals interfered by Galileo at these cities are lower than the global maximal value.

5. CONCLUSIONS

Due to exponentially increasing number of navigation systems, hand in hand with the new signals, including civil, commercial, and military signals, their is a need to assess radio frequency compatibility carefully. The design and implementation of any new signal has to be conducted carefully to avoid interferences. In other words, all GNSS signals and services must be compatible.

A more comprehensive methodology for the radio frequency compatibility assessment has been described, considering the geometry-dependence and time-varying terms such as space constellation, signal modulation, emission power level, space loss, satellite antenna gain, and user receiver characteristic. A detailed derivation of the methodology including equations and computation principle has beeen provided.

Real simulations were carried out to assess the interference effects where Galileo and Compass signals were sharing the same band. It is shown that the introduction of the Compass leads to the C/N_0 degradation, but the value is very small. In addition, the radio frequency compatibility in Asia-Pacific region has been analysed. As a conclusion, Compass can provide a sound basis for compatibility with GPS and Galileo.

At the end it has been pointed out that intersystem interference results shown in this paper are mainly referring to worst case scenarios simulations. Though the value is higher than normal value, it is feasible for GNSS system interference assessment.

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Contributors

Dr Wei Liu received PhD from Shanghai Jiao Tong University, Shanghai, China, in 2011. He is currently working at the Shanghai Maritime University. His research interests are: of signal processing, GNSS software receiver design, and GNSS related interference studies.

Dr Yuan Hu received PhD from Shanghai Jiao Tong University, Shanghai, China, in 2011. She is currently working at the Shanghai Ocean University. Her research interests are: signal processing, computer science, and GNSS related application studies.

Prof Xingqun Zhan received his PhD from Harbin Institute of Technology, Harbin, China. He is Professor of Navigation Guidance and Control at Shanghai Jiao Tong University, China. His main research areas include: GNSS technology and applications, and integrated navigation system.

Prof Chuanrun Zhai received his PhD from Harbin Institute of Technology, Harbin, China. He is Associate Professor of Navigation Guidance and Control at Shanghai Jiao Tong University, China. His main research areas include: Satellite navigation and pseudolites, and GNSS receiver design and performance.