Research on the Interference and Coexistence of CBTC in 1.8 GHz Band

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Abstract. The current Communication Based Train Control (CBTC) system is assigned to 2.4 GHz unlicensed band, which can be easily interfered. To enhance safety, the state radio regulatory commission assigned 1785 MHz–1805 MHz band to CBTC system. However, under the interference of first use telecommunication system in identical and adjacent frequency, it's a problem to guarantee the safety isolation distance between interfere and interfered party, so that to improve CBTC system safety. To solve this problem, this paper firstly analyzes relative domestic frequency assignment situation to determine interfere party, and then finds out study scenario based on field testing data. Afterward, obtain isolation distance between interfere and interfered party by ACIR modeling and deterministic calculations. Based on the research above, the advice that CBTC system should be assigned in 1790 MHz–1800 MHz band is given.

Keywords: 1.8 GHz · TDD-LTE · CBTC · Interference · Isolation distance

1 Introduction

Communication Based Train Control (CBTC) [1] system realizes bi-directional train ground communication, which makes the train break through from fixed blocked system to moving blocked system. And the ability of carrying capacity of a section is increasing by adding in-train entertainment information service, which has widely application prospect. However, China assigned CBTC system in 2.4 GHz unlicensed frequency band, which can be easily interfered by hand-held WiFi hot spot devices. As a result, several subway emergency brake accidents were caused in Shenzhen and Beijing. Security risks are brought out. To solve above issue, MIIT [2015] No. 65 document is published by China radio regulatory, which indicated that 1785 MHz–1805 MHz private band is assigned to TDD-LTE CBTC system, to enhance security of train transit. Besides that, CBTC system may apply 5G communication technology [3, 4] in forseeable future, which has higher spectrum efficiency.

However, under the interference of 3 kinds of first use telecommunication systems [5–7] in identical and adjacent frequency, it's a problem that guarantee the safety isolation distance between interfere and interfered party, so that to improve CBTC system safety. Reference [8–10] study on the overall framework, system function and interface specification of TD-LTE based CBTC system, respectively.

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Base on reference review of this paper, there is only 1 reference [11] focused on interference and coexistence of radio access system in 1785 MHz–1805 MHz frequency band, which includes CBTC system. Reference [11] applies deterministic calculations to study on interference and coexistence problem of 1785 MHz–1805 MHz radio access system base station and adjacent band IMT system base station. The security isolation between interfered and interfere base station is given, but radio access system downlink system interference is not take into consider.

Therefore, based on analysis on frequency distribution situation on 1785 MHz–1805 MHz, according to test and deterministic calculation methodology, this paper obtains the safety isolation distance between CBTC system and the other 4 interfere parties.

2 Frequency Assignment Situation in 1785 MHz–1805 MHz

2.1 Adjacent Frequency Assignment Situation in 1785 MHz–1805 MHz

According to reference [11] and [12], IMT spectrum assignment around 1.8 GHz in China is shown in Fig. 1. From Fig. 1 and reference [12], 1785 MHz–1805 MHz adjacent frequency is used for LTE FDD uplink in 1765 MHz–1785 MHz and GSM downlink in 1805 MHz–1820 MHz. GSM and FDDLTE network has wide coverage, especially in the city where CBTC has greater density. Therefore, it's necessary to study the interference of GSM downlink and FDDLTE uplink to CBTC terminal.

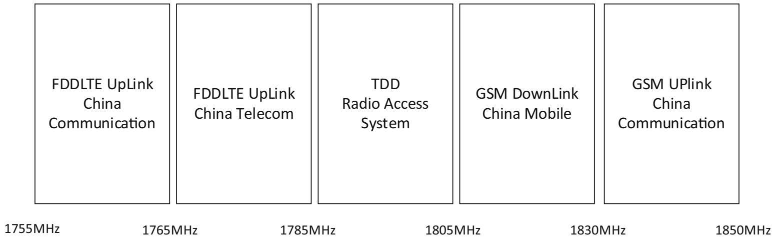


Fig. 1. Domestic frequency allocation situation in 1.8 GHz

2.2 Frequency Assignment Situation in 1785 MHz–1805 MHz

According to reference [2], 1785 MHz–1805 MHz is assigned to city rail transportation, electric, fuel and telecommunication industries. Currently, McWill broadband wireless access system has been deployed in this band. According to the data of The State Radio Monitoring Center,McWill system, which works in 1785 MHz–1805 MHz, is widely used in urban wireless access, heavy haul rail, petroleum fields, harbours, airports and other fields. The deployed McWill system has covered the entire 20 MHz band of 1785 MHz–1805 MHz. Single base station bandwidth range is [1 MHz–5 MHz], transmit power range is [1 W, 3 W], which is deployed over the ground. As the city wireless access systems, airports and other areas may overlap with the CBTC system operating area, it is necessary to study the interference of the McWill system to the CBTC train terminal.

3 Interference Scenarios

This section analyzes interference scenario requirement from systematic perspective. Afterwards, study scenario is determined from field test data.

As shown in Fig. 2, the interference source of interfered CBTC train is LTE FDD uplink, GSM downlink and McWill uplink and downlink. Therefore, interference from GSM base station, McWill base station, McWill terminal and LTE FDD terminal to CBTC train should be taken into consideration.

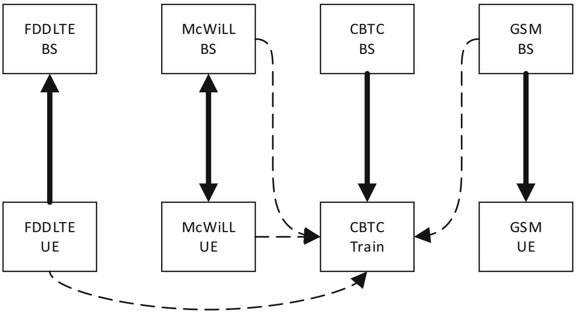


Fig. 2. Analysis on interference source to CBTC train

After determination of interference source, study scenario need to be found out. CBTC system can be divided to underground subway and over ground rail. The propagation environment is quite different. So test method is applied to determine CBTC train interference scenario.

To analyze scenario, by using test method in Beijing subway line 2, line 5 and line 13 underground and over ground respectively, the power level of 1710 MHz–1785 MHz, 1785 MHz–1805 MHz and 1805 MHz–1880 MHz can be obtained. The test settings can be found in Table 1, and test instrument and attachment list is shown in Table 2.

Table 1. Test setting

Setting	Value
Test frequency	1710 MHz–1785 MHz; 1785 MHz–1805 MHz; 1805 MHz–1880 MHz
Scan method	Clear Write
Internal attenuation	0 dB
Reference level	−10 dBm
VBW	1 MHz
RBW	1 MHz
Scan type	Auto
Pre-release state	OFF
Detection mode	Max Hold

Table 2. Test instruments and accessories

Device name	Version	Manufacturer
Spectrum analyzer	N9344C	Agilent
Lazer range finder	LRB5000	FeiXunDianZi
LapTop	X230	ThinkPad
Log periodic antenna	LM1250	FeiChuang

As shown in Fig. 3, test section of line 2 is underground, test section of line 13 is over ground, and test section of line 5 is combination of underground and over ground.

Beijing Line 2 Test Section

Beijing Line 13 Test Section

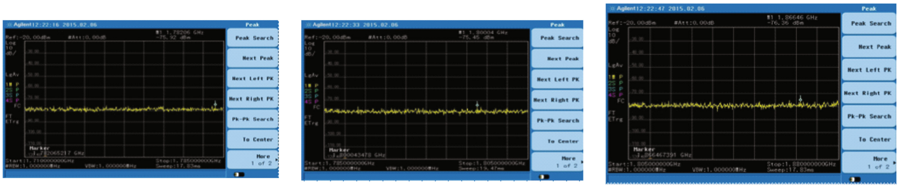
Beijing Line 5 Test Section

Fig. 3. Test section of CBTC

The test screen print for Beijing subway line 2, line 5 and line 13 can be found in Fig. 4. The test result of line 2 is shown in Table 3, line 13 in Table 4, and line 5 in Table 5.

As indicated in Table 3, when the train is underground, the power spectrum density stays stable and nearly identical. Since there is no McWill base station underground, −75 dBm/MHz– −74 dBm/MHz is almost underground electromagnetic environment background noise. This power spectrum density (PSD) matches the test result of line 5 underground part.

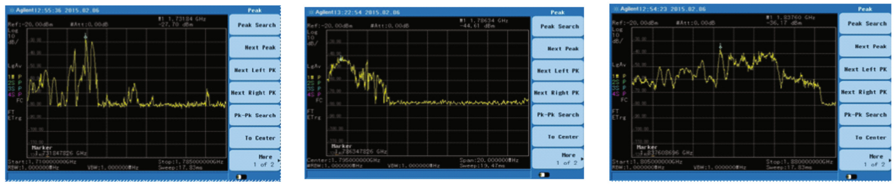
From Tables 4 and 5, we know when the train is over ground, the PSD of 3 test frequency band changes significant. 1710 MHz–1785 MHz over ground PSD is 35 dB higher than underground. And the result changes on various test interval, which is affect by uplink assignment and different population densities, like PSD in Xizhimen section is larger than other sections. The average value of 1785 MHz–1805 MHz over-ground is about −50 dBm/MHz, which changes on different test interval. For example, the PSD value of line 13 is larger than the one of line 5, which is related to McWill base station assignment density. According to in use radio station data from The State Radio Monitoring Center, Mcwill base station density along line 13 is higher than line 5, which matches test data. The average PSD of 1805 MHz–1880 MHz



Beijing Line 2, Test section from ChongWen to Qian Men, Reception Lever in 1710MHz-1785MHz

Beijing Line 2, Test section from ChongWen to Qian Men, Reception Lever in 1785MHz-1805MHz

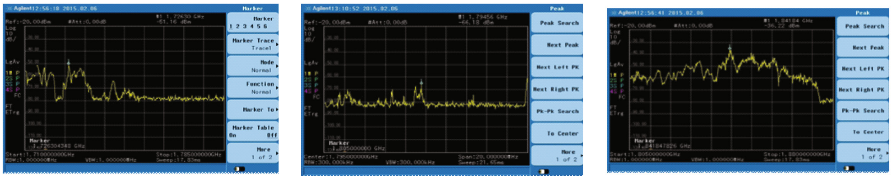
Beijing Line 2, Test section from ChongWen to Qian Men, Reception Lever in 1805MHz-1880MHz



Beijing Line 13, Test section from Xizhimen to Dazhongsi, Reception Lever in 1710MHz-1785MHz

Beijing Line 13, Test section from Xizhimen to Dazhongsi, Reception Lever in 1785MHz-1805MHz

Beijing Line 13, Test section from Xizhimen to Dazhongsi, Reception Lever in 1805MHz-1880MHz



Beijing Line 5, Test section from Lishuiqiao to Lishuiqiaonan, Reception Lever in 1710MHz-1785MHz

Beijing Line 5, Test section from Lishuiqiao to Lishuiqiaonan, Reception Lever in 1785MHz-1805MHz

Beijing Line 5, Test section from Lishuiqiao to Lishuiqiaonan, Reception Lever in 1805MHz-1880MHz

Fig. 4. The test screen print for Beijing subway line 2, line 5 and line 13

Table 3. Reception level testing result of Beijing line 2

Testing frequency band	1710 MHz–1785 MHz (dBm/MHz)	1785 MHz–1805 MHz (dBm/MHz)	1805 MHz–1880 MHz (dBm/MHz)
Section 1 Under ground	−75.92	−75.45	−76.36
Section 2 Under ground	−75.47	−74.98	−75.51
Section 3 Under ground	−75.62	−75.70	−74.72
Section 4 Under ground	−75.76	−75.18	−71.71
Section 5 Under ground	−76.36	−75.55	−74.82
Section 6 Under ground	−75.23	−75.76	−75.00
Section 7 Under ground	−76.24	−75.31	−75.88
Section 8 Under ground	−75.79	−79.68	−75.69
Average	−75.81	−75.95	−74.96

Table 4. Reception level testing result of Beijing line 13

Testing frequency band	1710 MHz–1785 MHz (dBm/MHz)	1785 MHz–1805 MHz (dBm/MHz)	1805 MHz–1880 MHz (dBm/MHz)
Section 1 Over ground	−27.70	−44.61	−36.71
Section 2 Over ground	−41.67	−56.22	−36.17
Section 3 Over ground	−35.74	−44.39	−33.96
Section 4 Over ground	−41.22	−43.76	−35.80
Section 5 Over ground	−49.36	−52.73	−34.21
Section 6 Over ground	−44.19	−56.33	−36.87
Section 7 Over ground	−49.36	−41.18	−38.40
Section 8 Over ground	−41.30	−61.17	−37.18
Average	−41.30	−50.04	−36.18

Table 5. Reception level testing result of Beijing line 5

Testing frequency band	1710 MHz–1785 MHz (dBm/MHz)	1785 MHz–1805 MHz (dBm/MHz)	1805 MHz–1880 MHz (dBm/MHz)
Section 1 Over ground	−51.16	−66.18	−36.22
Section 2 Over ground	−52.51	−61.40	−36.87
Section 3 Over ground	−53.91	−65.07	−39.08
Section 4 Over ground	−48.71	−64.41	−34.21
Section 5 Under ground	−75.45	−76.26	−76.19
Section 6 Under ground	−76.87	−76.11	−76.86
Section 7 Under ground	−75.98	−76.58	−76.79
Section 8 Under ground	−77.17	−75.54	−75.83
Average	−63.97	−70.19	−56.51

over-ground is about −36 dBm/MHz, and changes little in different sections, which is GSM downlink and related to stable density of GSM BS assignment. Moreover, the PSD of 1785 MHz–1805 MHz is smaller than other 2 bands, since Mcwill base station transmitting power is 6 dB smaller than GSM, and the number of public network UE is huge, etc.

According to above analysis, the CBTC downlink interfered scenario is chosen to be over-ground scenario. The upcoming scenario setting, parameter setting and propagation model should be set up as over-ground scenario.

4 Safety Isolation and Safety Isolation Distance

This section firstly introduces interfere and interfered RF parameters. Then ACIR of different situation can be obtained by calculation of interfere side's ACLR and interfered side's ACS. The secured isolation distance between CBTC train side and interfere side can be got from backward deduction of propagation model.

4.1 RF Parameters of Interfered and Interfere Sides

The system parameters [11, 12] of 4 kinds of interfere side can be found as Table 6. The RF parameters of CBTC system [10] can be found as Table 7.

Table 6. System parameters of 4 kinds of interfere side

System parameters	GSM BS	LTE FDD UE	McWill BS	McWill UE
Frequency band	1805 MHz–1820 MHz	1765 MHz–1785 MHz	1785 MHz–1805 MHz	1785 MHz–1805 MHz
Carrier bandwidth	200 kHz	5 MHz	5 MHz	5 MHz
Maximum transmit power	46 dBm	23 dBm	40 dBm	30 dBm
Thermal noise power spectral density	−174 dBm/Hz	−174 dBm/Hz	−174 dBm/Hz	−174 dBm/Hz
Noise figure	5 dB	9 dB	5 dB	9 dB
Cell radius	250 m	–	250 m	
Maximum antenna gain (including feeder loss)	15 dB	0 dB	15 dB	0 dB
Antenna height	30 m	1.5 m	30 m	1.5 m

Table 7. System parameters of CBTC system

System parameters	CBTC BS	CBTC Train
Frequency band	1785 MHz–1805 MHz	1785 MHz–1805 MHz
Bandwidth	5 MHz/10 MHz	5 MHz/10 MHz
Maximum transmit power	40 dBm/43 dBm	30 dBm/33 dBm
Noise figure	5 dB	9 dB
Maximum antenna gain(including feeder loss)	15 dB	0 dB
Antenna height	20 m	5 m
Protection criterion(I/N)	−6 dB	−6 dB
Receiving sensitivity	–	−93 dBm

4.2 ACIR Analysis and Calculation

It’s identical frequency interference that McWill system interferes CBTC system. And LTE FDD and GSM to CBTC system is adjacent frequency interference. 4 kinds of interference scenarios are taken into account in this paper: (1) The bandwidth of CBTC system is 5 MHz, which has 5 MHz frequency isolation with adjacent interfere system; (2) The bandwidth of CBTC system is 10 MHz, which has 5 MHz frequency isolation with adjacent interfere system; (3) The bandwidth of CBTC system is 5 MHz, which adjoin adjacent interfere system; (4) The bandwidth of CBTC system is 10 MHz, which adjoin adjacent interfere system. Since the modulation feature of GSMK, there is 200 kHz isolate bandwidth between adjoin GSM and CBTC system. To begin with, ACIR calculation model is introduced. Then, ACIR value of different interference situation is determined depending on the calculation of ACLR and ACS.

ACIR can be obtained by Eq. (1), where dB is applied as unit, and ACS is Adjacent Channel Selectivity, unit is dB.

$$ACIR = 10\lg\left(1/\left(1/10^{ACLR/10} + 1/10^{ACS/10}\right)\right) \tag{1}$$

Based on reference [13], Spectrum Emission Mask of LTE FDD can be found as Table 8.

According to different frequency interval and data in Table 8, subsection integration is applied to get the power leakage P(mW) from LTE FDD side to CBTC side. Then ACLR of different frequency isolation can be obtained by Eq. (2) as Table 9, where P_T is transmitting power of LTE FDD terminal, whose unit is dBm.

$$ACLR = P_T - 10\log(P) \tag{2}$$

Table 8. Spectrum emission mask of LTE FDD

Δf_{OOB} (MHz)	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Measurement bandwidth
±0–1	−10	−13	−15	−18	−20	−21	30 kHz
±1–2.5	−10	−10	−10	−10	−10	−10	1 MHz
±2.5–2.8	−25	−10	−10	−10	−10	−10	1 MHz
±2.8–5		−10	−10	−10	−10	−10	1 MHz
±5–6		−25	−13	−13	−13	−13	1 MHz
±6–10			−25	−13	−13	−13	1 MHz
±10–15				−25	−13	−13	1 MHz
± 15–20					−25	−13	1 MHz
± 20–25						−25	1 MHz

Table 9. ACLR from LTE FDD side to CBTC side in different frequency isolation

Case	Adjoin adjacent interfere/5 MHz bandwidth	Adjoin adjacent interfere/10 MHz bandwidth	5 MHz frequency isolation/5 MHz bandwidth	5 MHz frequency isolation/10 MHz bandwidth
ACLR(dB)	21.37	21.19	35.02	35.02

The ACLR model that GSM base station interferes CBTC Train is shown as Fig. 5.

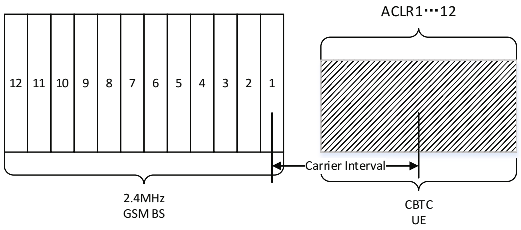


Fig. 5. The ACLR model that GSM base station interferes CBTC train

Based on reference [14], the spectrum emission mask of GSM base station can be found as Table 10. And according to reference [14] Sect. 4.2.1.1, subsection integration is applied on the specified measurement bandwidth and data in Table 10, to get the power leakage P(mW) from GSM base station to CBTC Train. Then ACLR that GSM base station interferes CBTC Train, in different frequency isolation can be obtained by Eq. (2) as Table 11.

CBTC train terminal belongs to TD-LTE terminal. Depending on reference [11], the ACS of CBTC train side can be obtained by Eq. (3).

$$ACS = P_{Interfer} - N - 10 * log10(10^{M/10} - 1) \qquad (3)$$

Table 10. Spectrum emission mask of GSM base station

Power level	100	200	250	400	≥ 600	≥ 1 800	≥ 3 000	≥ 6 000
≥ 39	+0,5	–30	–33	–60	–66	–69	–71	–77
37	+0,5	–30	–33	–60	–64	–67	–69	–75
35	+0,5	–30	–33	–60	–62	–65	–67	–73
≤ 33	+0,5	–30	–33	–60*	–60	–63	–65	–71

Table 11. ACLR from GSM side to CBTC side in different isolation cases

Case	200 kHz frequency isolation/5 MHz bandwidth	200 kHz frequency isolation/10 MHz bandwidth	5 MHz frequency isolation/5 MHz bandwidth	5 MHz frequency isolation/10 MHz bandwidth
ACLR(dB)	21.26	21.25	57.97	54.97

where $P_{Interfer}$ stands for in band blocking, whose unit is dBm. and N is noise floor, whose unit is dBm. M stands for uplift measure of noise floor whose unit is dB.

(1) ACS calculation of CBTC terminal interfered by GSM base station

According to reference [14], it's narrow band signal interference that GSM base station interferes CBTC terminal. However, the B/2 bandwidth narrow out band blocking limit is not given. Where B stands for system bandwidth of CBTC. To be more strictly, assume that $P_{Interfer}$ is identical between CBTC and GSM isolation 5 MHz or 10 MHz. Based on reference [14] Table 7.6.3.1–1 and reference [12], we know $P_{Interfer} = -55$ dBm.When CBTC bandwidth is 5 MHz, $N = -98.01$ dBm, $M = 13$ dB. And when CBTC bandwidth is 10 MHz, $N = -95$ dBm, $M = 10$ dB.

(2) ACS calculation of CBTC terminal interfered by LTE FDD terminal

Depending on reference [13], when the frequency interval between CBTC terminal and LTE FDD terminal is under 15 MHz, then it belongs to in band blocking. As a result, $P_{Interfer}$ is identical in situation 5 MHz and 10 MHz isolation between CBTC and LTE FDD system. Based on reference [13] Table 7.6.1.1–1, it can be found that $P_{Interfer} = -44$ dBm. When bandwidth of CBTC is 5 MHz, $N = -98.01$ dBm, $M = 6$ dB. And when bandwidth of CBTC is 10 MHz, $N = -95$ dBm, M = 6 dB.

The above calculation parameters are taken into Eq. (3). Then ACS of CBTC train side in different condition can be found in Table 12.

Table 12. The ACS of CBTC train side in different condition

Case	GSM interfere CBTC/Bandwidth of CBTC is 5 MHz	GSM interfere CBTC/Bandwidth of CBTC is 10 MHz	FDD LTE interfere CBTC/Bandwidth of CBTC is 5 MHz	FDD LTE interfere CBTC/Bandwidth of CBTC is 10 MHz
ACS(dB)	30.23	30.45	49.26	46.25

The ACLR and ACS obtained are taken into Eq. 1. The ACIR of 4 categories CBTC train interfered by interference system can be found as Table 13.

Table 13. The ACS of CBTC train side in different condition

Case	Adjoin adjacent interfere/5 MHz bandwidth		Adjoin adjacent interfere/10 MHz bandwidth		5 MHz frequency isolation/5 MHz bandwidth		5 MHz frequency isolation/10 MHz bandwidth	
Interfere side	GSM	FDDLTE	GSM	FDDLTE	GSM	FDDLTE	GSM	FDDLTE
ACIR(dB)	20.74	21.36	20.75	21.17	30.22	34.85	30.43	34.70

4.3 Calculation of Safety Isolation Distance

Safety isolation can be obtained by Eq. (4).

$$L_P = P_T + G_T + G_R - L_T - L_R - ACIR - I \tag{4}$$

P_T stands for maximum transmit interfere power, whose unit is dBm. And G_T is antenna gain of interfere system, whose unit is dB. G_R stands for antenna gain of interfered system, whose unit is dB. L_T stands for feed line loss of interfere system, whose unit is dB. And L_R stands for feed line loss of interfered system, whose unit is dB. *ACIR* is adjacent channel interference power ratio, whose unit is dB. *I* stands for maximum interference signal power of interfered system, whose unit is dBm, which can be obtained by protection principle of interfered system $I/N = -6$ dB.

Vehicle environment model [15] of UMTS is applied as BS to terminal path loss, which can be described as Eq. (5), where *d* is distance, unit is km, *f* is carrier frequency, unit is MHz, *H* is height of antenna, unit is m, *h* is benchmark roof height, which is set to be 15 m, and *s* is log normal distribution, which is set to be 5 dB.

$$L_P = 40 \cdot (1 - 4 \times 10^{-3} \cdot (H - h)) \lg(d) - 18 \lg(H - h) + 21 \cdot \lg(f) + 80 + s \tag{5}$$

PCS micro cell model [16] is applied as terminal to terminal path loss, which can be described as (6), where n_1 and n_2 are path loss index, which are valued 2.3 and 3.1 respectively, λ is wavelength, *d* is distance between transmit and receive antenna, whose unit is m, d_f is distance of first Fresnel zone, whose unit is m, *s* is transit path loss of 1 m, which can be obtained by free space model, whose unit is dB, *ht* and *hr* stand for antenna height of transmitter and receiver respectively, whose unit is m.

$$\begin{array}{ll} L_P = 10n_1 \lg(d) + s & 1 < d < d_f \\ L_P = 10n_1 \lg\left(d/d_f\right) + 10n_2 \lg\left(d_f\right) + s & d > d_f \\ d_f = \frac{1}{\lambda}\sqrt{16h_t^2h_r^2 - \lambda^2\left(h_t^2 + h_r^2\right) + \lambda^4/16} & \end{array} \tag{6}$$

By taking data of Tables 6, 7 and 13 into Eqs. (5) and (6), the safety isolation and isolation distance between CBTC train side and interfere system can be found in Table 14.

Table 14. Isolation and isolation distance between CBTC train and interferes in different condition

Case	Adjoin adjacent interfere/5 MHz bandwidth		Adjoin adjacent interfere/10 MHz bandwidth		5 MHz frequency isolation/5 MHz bandwidth		5 MHz frequency isolation/10 MHz bandwidth	
Interfere side	GSM	FDD LTE	GSM	FDD LTE	GSM	FDD LTE	GSM	FDD LTE
Safety Isolation (dB)	138	102	135	100	128	89	125	86
Isolation distance (km)	1.427	0.384	1.187	0.331	0.773	0.146	0.643	0.117
Case	Same frequency band/5 MHz bandwidth		Same frequency band/10 MHz bandwidth					
Interfere side	McWill BS	McWill UE	McWill BS	McWill UE				
Safety Isolation (dB)	156	128	153	131				
Isolation distance (km)	4.297	2.64	3.576	3.31				

From above analysis, the isolation distance between GSM base station, LTE FDD terminal, McWill base station, McWill terminal and CBTC train side is quite long. It is inappropriate to deploy CBTC system in the area where McWill system exists. The method that assigns CBTC system in 1790 MHz–1800 MHz can be used to realize minimum isolation distance between CBTC system and interfere systems. However, only apply isolation distance measures is not enough. For example, when CBTC system works in 1790 MHz–1800 MHz band, safety isolation between CBTC train and GSM base station is 0.643 km. The cell radius of GSM is 250 m, which can not fulfill isolation distance requirement. Hence, additional isolation measures are needed to guarantee that GSM base station and LTE FDD terminal do not cause harmful interference to CBTC system.

5 Conclusion

To solve 1785 MHz–1805 MHz CBTC downlink interference problem, this paper firstly analyzes domestic identical and adjacent frequency band assignment situation. Then this paper finds out study scenario based on field testing data. Afterward, this paper calculates isolation distance between interfere and interfered party by ACIR modeling and deterministic calculations. Depending on the research results mentioned above, the advice is given that CBTC system should be assigned to 1790 MHz–1800 MHz.

References

1. Wan, Y., Wang, D., Mei, M., Waterman, M.S.: Composable modeling method for generic test platform for CBTC system based on the port. J. Int. J. Adv. Comput. Sci. Appl. 12(6) (2015)
2. MIIT No. 65 Document (2015)
3. Zhang, H., Dong, Y., Cheng, J., Hossain, Md.J., Leung, V.C.M.: Fronthauling for 5G LTE-U Ultra Dense Cloud Small Cell Networks. IEEE Wirel. Commun. **23**(6), 48–53 (2016)
4. Zhang, H., Liu, N., Chu, X., Long, K., Aghvami, A., Leung, V.: Network slicing based 5G and future mobile networks: mobility, resource management, and challenges. IEEE Commun. Mag. **55**(8), 138–145 (2017)
5. Wang, C.Y., Wei, H.Y., Chen, W.T.: Resource block allocation with carrier-aggregation: a strategy-proof auction design. J. IEEE Trans. Mob. Comput. **15**(12), 3142–3155 (2016)
6. Cui, Y., Yang, L., Liu, B., Li, R.: Multiband planar antenna for LTE/GSM/UMTS and WLAN/WiMAX handsets. J. IET Microwaves Antennas Propag. **10**(5), 502–506 (2016)
7. Zhu, G.: McWill and its applications in power communication system. [J]. Telecommunications for Electric Power System (2009)
8. Terminal Equipment Specification for LTE-M. http://www.camet.org.cn
9. General System Architecture and Function Specification for LTE-M. http://www.camet.org.cn
10. LTE-M Interface Specification for CBTC. http://www.camet.org.cn
11. Jingdi, L., Jian, F., Ge, M.: Research on Interference and Coexistence between Radio Access System in 1785 MHz–1805 MHz Band and Adjacent IMT System. Technical report, CCSA TC5 WG8 82th Meeting, Chang Sha (2016)
12. Liyan, Y., Jian, J.: Research on Interference and Coexistence between GSM in 900/1800 MHz Band and LTE(FDD/TDD). Technical Report, CCSA TC5 WG8 63th Meeting, Zhang Jia Jie (2013)
13. 3GPP TS 36.101 V13.5.0(2016-09). http://www.3gpp.org/DynaReport/36-series.htm
14. 3GPP TS 45.005 V13.2.1(2016-09). http://www.3gpp.org/DynaReport/45-series.htm
15. 3GPP TR 36.942 V13.0.0(2016-01). http://www.3gpp.org/DynaReport/36-series.htm
16. Propagation Model. http://wenku.baidu.com