Upgrade of Signaling System on the Rapid Transit Systems

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Abstract：In this paper, discuss the upgrade system for an old type and extend to new line system of signaling at Taipei Rapid Transit Systems (RTS). Since the track circuits of fixed block are utilized the frequency loops and audio frequency track circuits of train position detected on the automatic train protect system. At present, Neihu line is the new extension construction of Muzha line, due to the new singling system as Communication Based on Train Control (CBTC) has use the new system and upgrade with revenues service system on the Muzha line. How do check and integration between old and new type systems to combination and compatible for the train running of Automatic Train Control (ATC) system shall importance issue. The CBTC system is used the simply construction technology with application to upgrade at Metro systems. In theme also comparison between fixed blocks and moving blocks circuits for conception of design in the Taipei RTS, and study of CBTC system technology manipulate on the system upgrade.

Key-Words: CBTC, moving block, intelligent transportation, intelligent vehicle, signaling.

1 Introduction

In 1996, the revenues service of Mucha line at Taipei Medium Capacity Transit System (MCTS) was opening. In 1997, the Taipei Mass Rapid Transit System (MRTS) was opened as the first heavy-capacity transit line in Taiwan. Six lines (Danshui, Zhonghe, Xindian, Banqiao, Tucheng and Maintenance line) operated continually as Fig.1. The Neihu line is extend by Mucha line of MCTS, it is required the system design and operation compatible with Mucha line and also the trains should pass though both of new and old line [1]. On hand the signaling system of Mucha line will upgrade and integrate into the new system with Neihu line. The old system will annex by CBTC system technology. That is result of the Mucha line was sole signaling system to compatible with the other system for extension and could be sufficiently pass one train directly from Neihu line to Mucha line combination between different systems of signaling. Also Circular line and other extension line define the specification is allow to the choose compatible either CBTC system technology in the future.

CBTC system is uses an intelligent vehicle control systems, and system control and data transmission between train and wayside and Vehicle Control Center (VCC) use the radio communication. Control region of signaling boundary between radio cells.

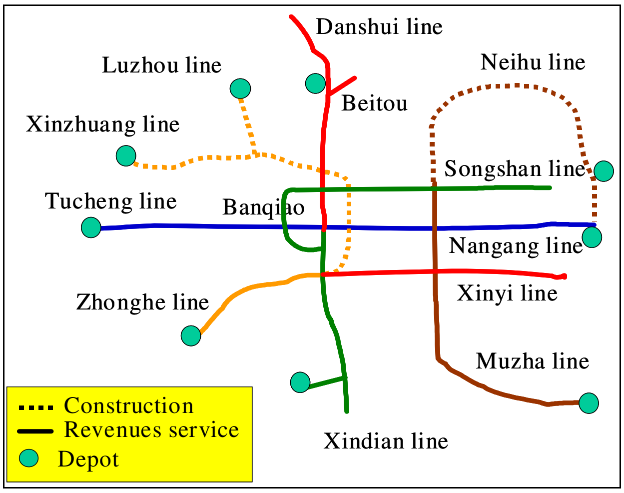

Fig. 1 Taipei metropolitan area rapid transit system drawing.

2 Status of ATC Systems

ATC systems of signaling frame consist of Automatic

Train Operation (ATO), Automatic Train Protection (ATP) and Automatic Train Supervisor (ATS), which are redundancy require of the signaling system in the Taipei MRTS and MCTS.

2.1 Conception of Signaling on Taipei MCTS

For system design, the signals data transmission and receiver between train and wayside communications are use loop detection as well as the Transmission Line Assembly (TLA) systems at Muzha line of Taipei MCTS. TLA device is including basics 3 loop with safety frequency loop, positive detection loop and stopping program loop (Fig.2).

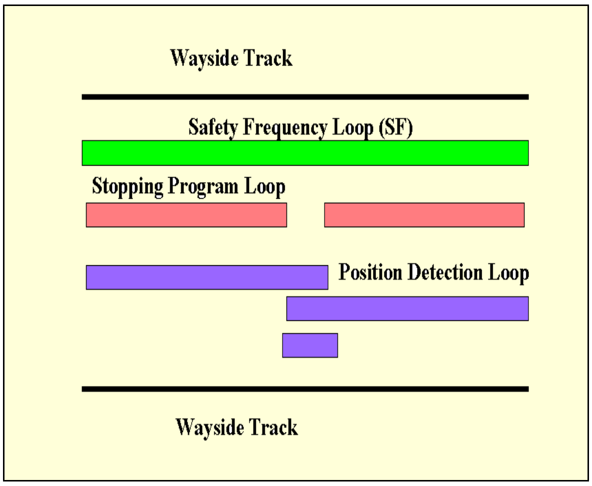

Fig. 2 Wayside loop coils on Muzha line of MCTS.

As for on-board ATC with wayside fixed ATC system are arrange in pairs to proceed on system communication signals control and train status for program function and its deal to emergency and safety signals.

2.2 Conception of Signaling on Taipei MRTS

The Audio Frequency (AF) track circuits system that is application to the train detection and speed code transmission of the ATP system in Taipei MRTS. Train running control utilized an audio frequency carrier on rails of mainline. The main function and signals task performance as show in Fig.3.
An audio frequency track circuits system is part of ATP system, it is used by fail-safe protection for the system safety design. Track circuits have distribute many blocks for the data transmission interval between track circuits, and according to environments and conditions of the site situation that make divide from blocks length with distance between 30 meter and 400 meter. In each blocks have set up different frequency to detect train position, therefore collocated the 8 frequencies to make up the detection track circuits for ATP wayside system on Taipei MRTS as define F1 to F8 show in Fig.4.

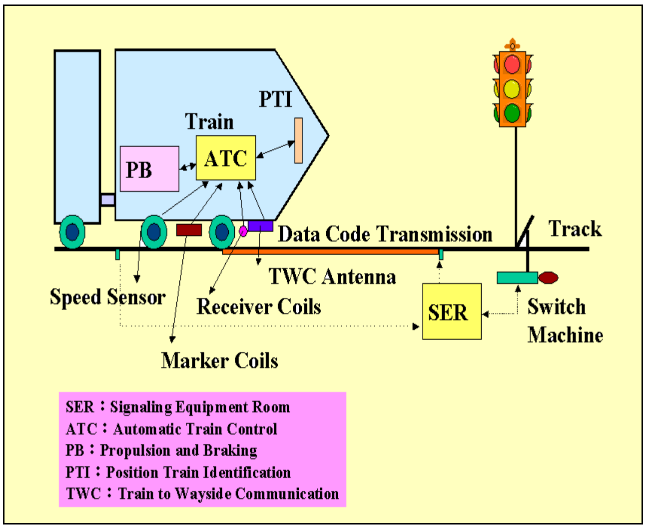

Fig. 3 ATC system control drawing at Taipei MRTS.

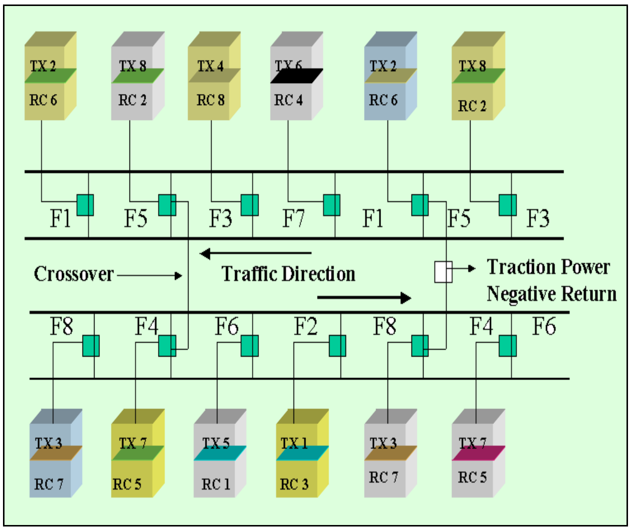

Fig. 4 Distribution frequency blocks diagram for train detection in the AF track circuits.

The track circuits of signaling have sorted by two kinds of signals. One of the detection train on track, using in carrier frequency range 2970Hz~4950Hz at 2~3Hz code rate with F1~F8 blocks establish in up and down track circuits. Another of the communication signals between train and wayside, that including speed command are received by carborne equipment by an amplitude modulated carrier frequency 2340Hz at code rate to make out speed code, door right and left open function, identification code and relation message data to use as frequency shift key which on Train to Wayside Communication (TWC). The vehicle berthed by the signals transmit of frequency carrier modulated at a code rate handle for the ATP berthing alignment[2].

3 CBTC System Design

At present, on technology development of CBTC system is belong to the Global System for Communications (GSM) and digital communication of the Code Division Multiple Access (CDMA) and Wide-band CDMA (WCDMA) and Orthogonal Frequency Division Multiple Access (OFDMA) applied to the Metro system in the world. AF track circuits or loop conductor upgraded by CBTC system that the benefit is simple for replacement and united integration. Specially, CBTC system has provided a standard, powerful function, simple system and convenient equipment, system nimble and expand, so it is prompt to turn into the modern times with main currently ATC for the running of signaling system on the RTS. The railway of ATP utilized the loop conductor with wayside equipments up to now that is become without wayside equipment and cable installation upgraded by radio communication of ATC system.

3.1 CBTC Standard Toward

CBTC system that is enhanced operational flexible and powerful function with the communications are utilized the Radio Frequency (RF) of ATC system for the continual data transmission between vehicles and wayside system, is basis upon the ATC Unit whole. CBTC has involved complication interface as vehicle control, vehicle network, signaling data transmission and RF communications etc., consider that the system costs, benefits, proprietary technology, intelligent technology, interface, system safety, system extension and security protection, those are established the CBTC systems with IEEE standard as Table 1 [3-7].

Table 1. IEEE Standards on CBTC System Interface [3-6].

Standard No.	Name	Issuance
IEEE-1473	Communications Protocol Aboard Trains	1999
IEEE-1474.1	Communications Based Train Control	1999
IEEE-1474.2	Standard for User Interface Requirements in Communication Based Train Control System	2003
IEEE-1475	Functioning and Interfaces Among Propulsion, Friction Brake, and Trainborne Master Control on Rail Rapid Transit Vehicles.	1999
IEEE-1476	Passenger Train Auxiliary Power Systems Interface	2000
IEEE-1477	Passenger Information System for Rail Transit Vehicles	1998
IEEE-1478	Environmental Conditions for Transit Rail Car Electronic Equipment	2001
IEEE-1482.1	Rail Transit Vehicle Event Record	1999
IEEE-1483	Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control	2000
IEEE-1488	IEEE Trial-Use standard for Message Set Template for Intelligent Transportation Systems	2000
IEEE-1489	Data Dictionaries for Intelligent Transportation Systems.	1999
IEEE-1512	Common Incident Management Message Sets Use by Emergency Management Centers	2000
IEEE-1512.1	Traffic Incident Management	2003
IEEE-1512.3	Hazardous Material Incident Management Message Sets for Use by Emergency Management Centers	2002
IEEE-1536	Rail Transit Vehicle Battery Physical Interface	2002
IEEE-1570	Interface Between the Rail Subsystem and Highway Rail Intersection	2002
IEEE-802.11	Wireless LAN Medium Access Control and Physical Layer Specifications	1999

For vehicle interface with subsystems network standard as per IEEE-1473-L deployed on the rail transit vehicle standard and interface specification, shall allow for two or above differential of vehicle contractor and difference equipments to combine with data link. This standard and technology shall deployed for the acceptance and expand in the RTS. That has provided with high compatible, secure, high availability, flexibility, common mode and fault tolerant system as Fig. 5.

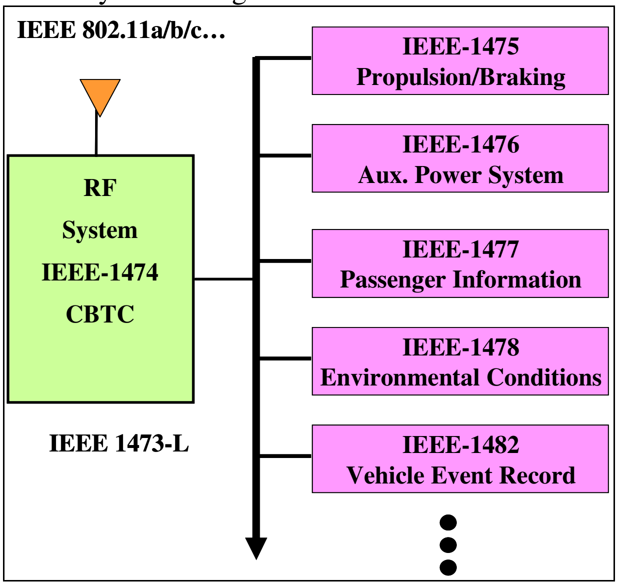

Fig. 5 CBTC standard bus on the vehicle interface.

3.2 A Profile of Moving Block

The evolution of the moving block is from the fixed block. The braking distance was difference between the moving block and fixed block. In the fixed block, the braking distance between two trains_kept by three steps of the speed control from the blocks of track to the following train. Its brake function is based on the ATO model. It is need to maintain a block on ahead of a train with the following train between Safety Braking Distance (SBD) for the ATO system protection.

In order to shorten the braking distance and headway of fixed block, the profile of braking distance of the moving block is modified into single-step speed for the following train (Fig.6).

The single-step speed control can provides a braking curve of trains with stable and smooth. The control system for the speed profile utilizes the on-board ATC system included the train database to decide the speed code command and other parameters to assure safety braking distance.

In order to ensure safety, the VCC conveys the train position to the onboard database for any train. The database determines the profile of braking distance in accordance with the position of the ahead train and to get the most safety on braking distance for the following train.

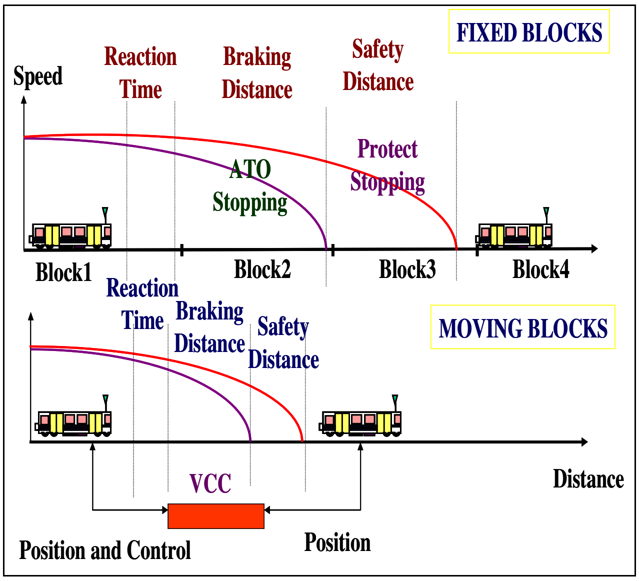

Fig. 6 Compare between fixed blocks and moving blocks.

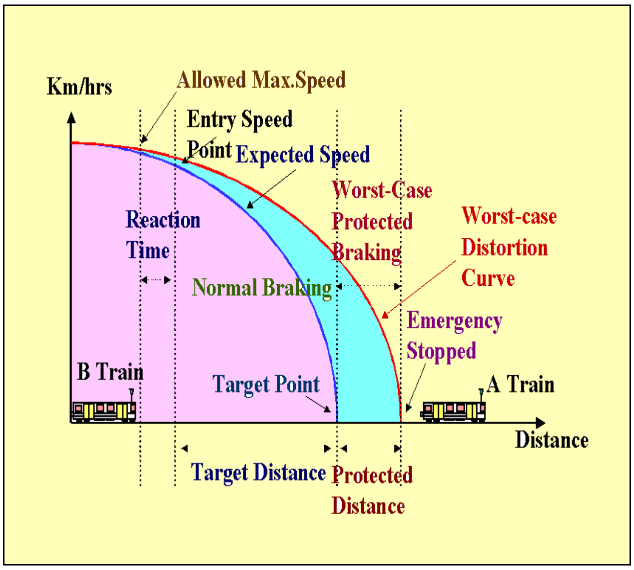

Fig. 7 SBD profile of CBTC system.

For example, when the speed of a train is decreased without stop then increase speed in an instant, and then keep uniformly accelerated motion. Simultaneously, the following train will corrected the SBD profit and its speed will also to follow up the ahead train. Therefore, the SBD and headway timing should be cut down between the two running train in a section by the nimble train speed control and software of the onboard database (Fig. 7).

CBTC train position detection use the normal pointer (tag) to verification as shown Fig.8. In the wayside install a lot of tags, one region included many tags.

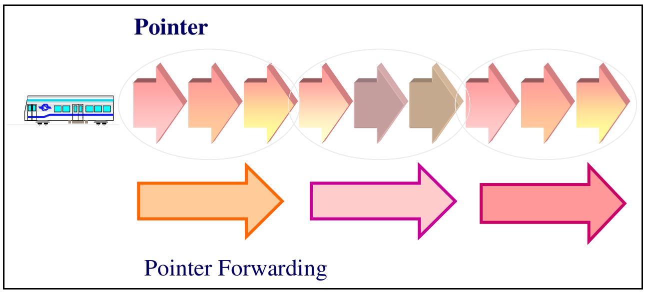

Fig. 8 CBTC pointer with region.

4 RF-ATC Systems

4.1 Conception of Radio ATC system

The radio communication standard that is following IEEE-802.11a with 2.4GHz frequency band-wide and IEEE-802.11b with 5GHz frequency band-wide Which is transmission baud rate of IEEE-802.11a with 9,12,18,24,48 and 54Mbps, and IEEE-802.11b to increase following with 5.5Mbps and 11Mbps, those are stored by the network and in coordination with the CBTC system application of intelligent transportation system.

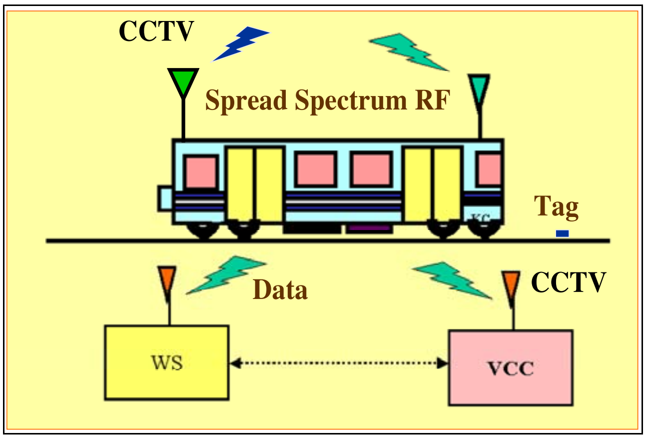

Fig. 9 RF ATC systems.

The new ATC system has developed for the radio train control system. The ATC system monitoring data and train position applied the Wayside Radio Station (WS) and VCC to collected information as shown Fig 9. In accordance with an area of WS and train drive on a region, the trains utilize the onboard database to calculate the distance between trains, speed profile, Safety, SBD, temporary speed region, braking rate, wayside slope and track bending for deciding the best safety braking distance.
The radio ATC of moving block has the characteristic feature as follows:

A. Intelligent Vehicles
B. Radio Based communication
C. Infrastructure Database
D. Moving Blocks
E. Beacon device

4.2 Intelligent Vehicle

Vehicle subsystem has two database performed: (1) infrastructure database is dominated by system message for the control and detection safety as switch locations, station stop points, beacon locations, section radio frequencies, speed restrictions, track speed limits, grades etc. (2) database is dominated by reaction time, service brake rate, safety brake rate, emergency rate, brake switch operation time, brake build up time, tachometer scale coefficient, wheel size, distance counter, default train length, acceleration rate, decrease rate and speed profile etc. The infrastructure database was built an intelligent vehicle subsystem on RF CBTC for moving blocks (Fig.10-11).

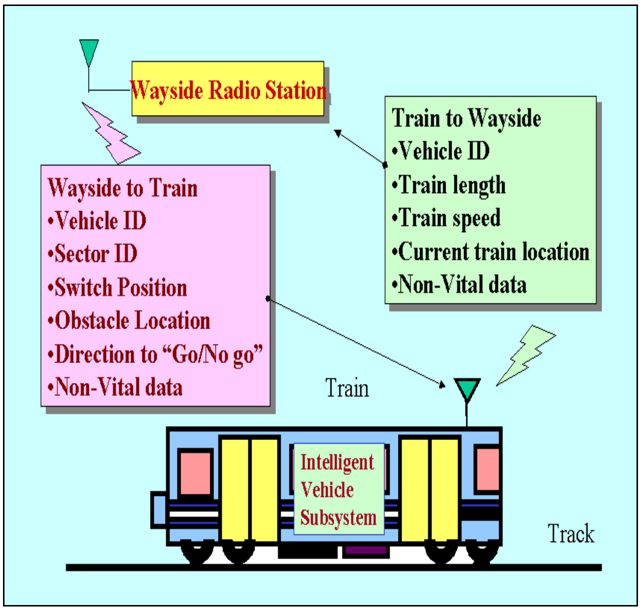

Fig. 10 Communication between intelligent train and wayside.

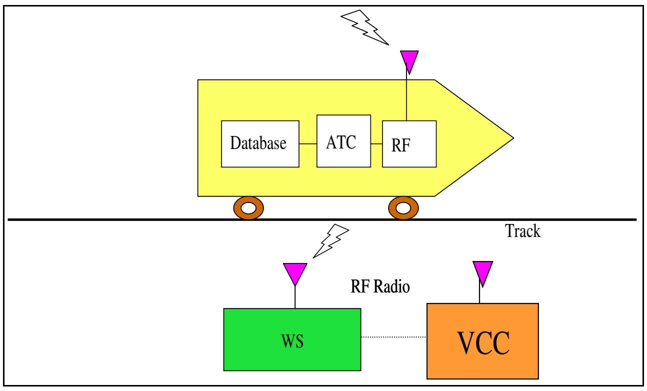

Fig. 11 Communication between intelligent train and wayside and VCC.

4.3 Communication between Train and

Wayside

CBTC system rely both side continuous digital communication between train and wayside controller. Radio ATC system is the communication medium between train and wayside radio station (WS) to transmission data message. The transmission data message includes the ID code to confirm the data correction. Fig.12 illustrates the communication between train and wayside.

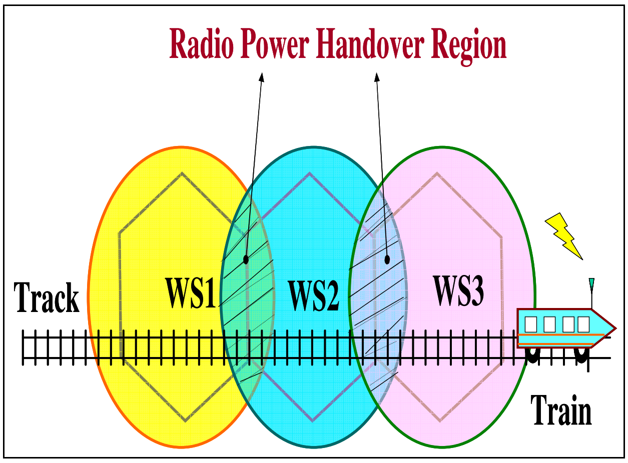

Fig. 12 The frame code division between WS systems.

The communication between radio ATC and WS is performed by cable that can be copper cable, coaxial cable or optical fiber. The wireless communication between WS are cells on same frequency, and the cover area shall have a frequency conflicted by time division multiple access or frequency division multiple access. By the way, the CDMA and WCDMA is development fast. Now, the spread spectrum communication and Pseudo-Noise (PN) are applied in the wide spectrum technology. In Fig.12, WS1, WS2 and WS3 cell have common area of frequency region with the orthogonal of PN code to differentiate between channels and operation. The Pulse Code Modulation (PCM) or high-speed network is the data transmission way of each WS. In general, there is about 1.5 Km distance between WS, or a basis on an area size. It is complicate to determine these transmission distance.

VCC provides the data collection between all WS though the PCM or other communication technique. VCC utilizes PC-base computers for system operation and calculation due to their high performance. Radio ATC system power handover is the key problem in signal transmission technology between WS (Fig. 13-14). The train has to maintain running and RF system has to keep the radio data transmission of each WS.

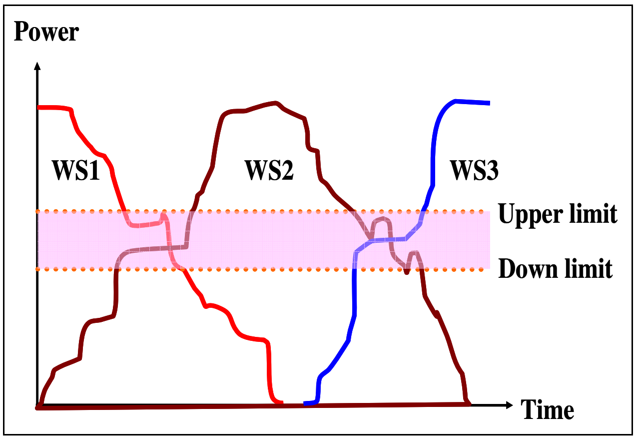

Fig. 13 Power handover between WS.

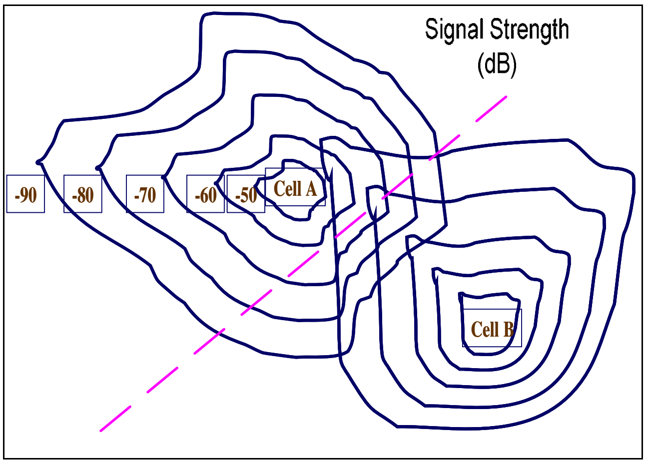

Fig. 14 Actual radio cell region.

4.4 Conceive of EMI

The antenna of CBTC communication systems conceive of EMI interference, such as a super-antenna. In the meanwhile, signaling and communication systems between train and wayside shall receive radio frequency and noise at track surrounding, these are as radio and mobile communication, television, satellite and noise etc.

According to the Railway Industry Association specifications that susceptibility levels of 20V/m over the frequency ranges 27~500MHz as required, and compare European Generic Standard Cenelec specifies the immunity level to be 10V/m over the frequency range of 30MHz~1GHz was standard on the EMI as required to design the system protect [16-17].

Due to the radio communication between train and station or both station are utilized the UHF channel with range 300MHz~3GHz, both sides transmitted and received by emission and microwave concern for EMI. A basis from every aspect of data collected to make the frequency distribution of environment status for the radio communication on the Taipei metropolis as shown in Table 2.

In the Taipei city, among of maximum power of 20KW by radio emission of television station and minimum power of 1~2 watt by wireless communication, CBTC use the 2.4GHz to data transmission and spread spectrum of metro system, that is isolation EMI interference for the system operation.

Table 2. Distribution Frequency of Radio Communication at Taipei Metropolis

Wireless communication	Frequency range	Remarks
Mobile Phone GSM900 GSM1800	890~960MHz 1710~1880MHz	Cell shoot power about 5W to 60W
Television Station	174~180MHz(Taiwan TV) 186~192MHz(China TV) 198~204MHz(Chinese TV) 162~168MHz(People TV) All base on north area of Taiwan	TV Station projectile power 20KW and signals transmission about 100Km
Mobile phone, multimedia, Digital communication in the future	800MHz~10GMHz	CDMA、TCDMA、WCDMA、OFDM etc, in the future
Radio：Police, sausage clan Ham clan	20~500MHz (Minority used 10KHz~1MHz) 1.8MHz~250GMz(1~18 rank)	Same illegal utilized of frequency channel very active for Sausage clan and ham clan
Train radio communication	300MHz~3GMHz	Shoot power about 3W
Microwave	1GMHz~300GMz	Projectile power about 1~2w

Due to EMI source shall affect the CBTC system, EMI interference give classify of the internal and external interference. Internal segment included track inside of the traction power and emission and other noise, another external included around electromagnetic, microwave, radio, lightning, thunder, noise and transient etc. Comprehensive to explain, affect for EMI to antenna of CBTC system as following:

(1). Internal of track to give rise to:
1). Traction power harmonics
2). Propulsion harmonics
3). Capacitance, Inductance, Impedance.
4). Electromagnetic radiation.
5). Transient and Surge.
6). Signals and noise.
7). Braking reaction.
8). Propulsion motor.
9). GTO operation and control
10). Traction power leakage current.
11). Power source.
12). Air condition.
13).Other.

(2). External of track EMI source
1). Radio communication.
2). Thunder and lightning.
3). Microwave.
4). Electromagnetic radiation and field.
5). Automobile, airplane, horn.
6). Workshop.
7). Signals and noise.
8). Wireless communication.
9). TV power emission.
10). Car noise.
11). Other.

5 Spread Spectrum

5.1 Spread Spectrum Techniques

Widening the transmitted spectrum refer to the Signal(S)/Noise(N) radio conception, spread spectrum signal since a wideband signal is transmitted, recall that the output S/N radio and FM processing gain(G) are given by following[8]:

$$(\frac{S}{N})_{out} = \frac{3}{\beta^2}(\frac{S}{N})_{in} = G(\frac{S}{N})_{in} \text{...........(1)}$$

Where(S/N)out：Output S/N radio
β ：Modulation index,
(S/N)in=Input S/N radio, G =FM processing gain

In addition the theoretical capacity of any communication channel is defined by C.E. Shannon's channel capacity formula [14]:

$$C = B_\omega \log_2\left[1+\frac{S}{N}\right] \text{.......................(2)}$$

Where B_ω =Bandwidth in Hertz,

C=Channel capacity in bits per second,
S=Signal power,
N=Noise power.

The system processing gain Gp quantifies the degree of interference rejection. The system processing gain is the ratio of RF bandwidth to the information rate and is given as [15]:

$$G_p = \frac{B_\omega}{R} \qquad (3)$$

Where G_p=System processing gain,
R=Information rate.

5.2 Future RF CBTC Signals

The technique on WCDMA or OFDMA should be upgraded by the new radio ATC signals. TRTS transmission system will employ the new digital communication technology.

In the future, the new RF CBTC system is going to utilizing digital communication as WCDMA. In other word, data transmission from VCC to WS then to the train should be upgraded by the following new technology：

A. Spread spectrum communication
B. Trellis code modulation
C. Error control coding
D. QPSK modulation
E. System hardware and software.

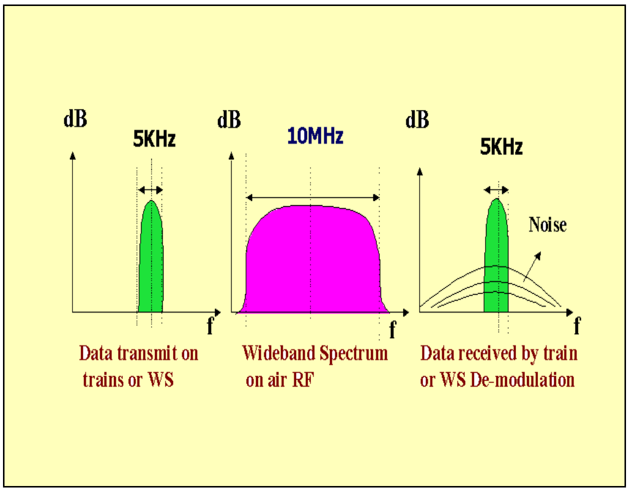

Fig. 15 Spread spectrum between train and wayside.

The development of the communication techniques on the new radio ATC system use for spread spectrum (Fig. 15). That provides the excellent immunity on EMI, noise and other radio signals. These techniques called pseudo-noise system are utilized for transmitter and receiver to carrier in data signals of train or WS. The transmitter carrier provided a signal-to-noise ratio and a bandwidth on channel combination of both. It is used for transmission modulating the carrier frequency and receiver de-spectrum and de-modulating. The codes of the receiver signal must synchronization for the original data can be recovered.

Moreover, regarding the computer software and the hardware application on the communication system, its demand service, real time steaming and the risky theory of had the discussion [9-12].

6 Comparison Systems

At present, the various signals manufacturer have not followed CBTC standard regarding the IEEE recommended that the modular design and production, besides IEEE-1473 and a part of IEEE-802.11. The majority of the signaling manufacturer all the first protection itself specialized technology and the specification produces the CBTC system, will let the competition manufacturer be unable to substitute or accommodatingly to on his system, so may hold his monopoly, and will obtain following service spare parts own benefit.

Table 3.Comparison between CBTC and Fixed Blocks

Parameters	**CBTC**	**MRTS Fixed Blocks**	**MCTS Fixed Blocks**
Minimum Headway	30~70 Sec	105 Sec	72 Sec
Maximum number of train that can be processed by a single wayside controller	10~40 trains	1-10 Trains	1-10Trains
Resolution of train speed measurement for ATP purpose	±0.5kph~±2kph	±1kph	±1.6kph
Accuracy of measured train location PSS	±5cm	±25-30 cm	±25cm
Accuracy of measured train location during normal operations	±5m~±10 m	±10m	±5m~±10m

Train—Wayside data communication	Wireless LAN 2.4GHz	Carrier signals and magnetic field transfer transmit 0~10kHz	Carrier signals and magnetic field transfer transmit 0~10kHz
Train network protocol	IEEE-1473-L	Has not provided standard	Has not provided standard
Train Position Detection	Tag (Without cable)	Fixed Blocks (Cable)	Fixed Blocks (Loop and Cable)

In the Table 3, compared with CBTC and Fixed Blocks function characteristic, the CBTC function surpasses Fixed Blocks obviously, in particular minimum headway, design of the CBTC standard is 30-70 Sec, for example the Taipei MRT systems that actually can achieve 105 Sec and MCT of the Muzha line is 72 Sec. Regarding the wayside controller processing biggest train quantity of Signaling, the CBTC standard stipulation is maximum number as 10 to 40 trains that can be processed by a single wayside controller, but Fixed Blocks one wayside controller may control 6 to 8 stations, its processing train number may achieve above 10 trains, but the Taipei MRT one station use one controller, therefore cost , maintenance and function of CBTC shall extremely good than fixed block.

7 Conclusion

In accordance with the powerful function, simply construction, small volume, easy maintenance, litter space to installation of equipments and decrease duct, CBTC System is dominate and upgrade for the signaling in the metro system.

This paper introduced the development of CBTC and its application based on the new RF communication and standard with advanced techniques. As the technique on the CDMA or WCDMA and IEEE Standard of RF communication is completed, it is strongly recommend for a RF CBTC systems in a vital track transportation system. The future works on the good transport of Metro systems are the power handover and signals communication between wayside and trains system stability and reliability.

Therefore CBTC follow IEEE Standard to integrate the different manufacturer of the signaling systems, this still waited for the proprietor and manufacture strive to expand. The specifications of CBTC system apply to the international standard are difficult to resist for the majority manufacturer monopoly on them technology and market, at present the expressed that still had perplexed at technology and compatible question waiting for overcoming competition psychology. Uses the international standard need to invest the research and development cost, only if has the lure or the owner puts forward the advantage, or various manufacturers can have tolerant towards state, each other's trusts , the time tendency demand, this goal will be achieve in the future.

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