



TETRA FOR DRIVERLESS RAPID TRANSIT SYSTEM

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SUMMARY

This paper identifies the attributes of a radio communication system that are essential for the operation of a driverless rapid transit system, and discusses how these requirements may be fulfilled using a Terrestrial Trunked Radio (TETRA) system. The design of the TETRA system in the Singapore Circle Line, a project that is currently under construction, is also briefly introduced.

Some useful experiences that have been gained from the implementation of TETRA for the Singapore North East Line project, and how these are addressed in the CCL radio system design are also discussed.

1 INTRODUCTION

Radio communication system is an integral part of today's highly integrated and automated railways. In comparison with railway systems where trains are operated by drivers, driverless railway systems are more reliant on highly available and reliable communications for their safe and efficient operations.

In this paper, we share our views on the requirements of the radio system for a driverless rapid transit system, and discuss how these requirements will be implemented in the Singapore Circle Line (CCL) Mass Rapid Transit (MRT) project using the Terrestrial Trunked Radio (TETRA) system.

We also share in this paper, some useful experiences that we have gained from the implementation of the Singapore North East Line (NEL) radio communications system and how these will be addressed in the CCL project.

2 RADIO SYSTEM FOR A DRIVERLESS SYSTEM

On trains operated by drivers, the main purpose of the trainborne communications system is to provide the driver with a means to communicate with commuters in train, as well as with operators in the control centre. Commuters on trains can speak with the driver using the train intercom to seek immediate assistance when need arises.

The railway Operation and Maintenance (O&M) personnel also uses the radio communications system for their daily routine operation, as well as emergency response activities.

In the case of a driverless system, operators from the remotely located Operation Control Centre (OCC) will have to attend to calls for assistance from commuters through the radio communication system. The radio system serves as the communication bridge between the commuters and the OCC, carrying with it essential services such as passenger intercom and public address announcements to the trains. These important facilities will enable the OCC to react promptly, and to extend timely services to the commuters when need arises.

For a manually driven train, operating status of the trainborne equipment is presented to the driver through audio and/or visual indications. He will take the necessary actions should abnormalities be detected.

The information flow for radio communication links for a manually driven train is depicted in Figure 2.

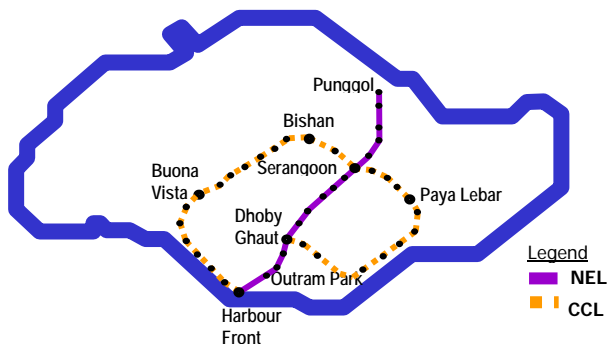


Figure 1 – Singapore North East Line and Circle Line

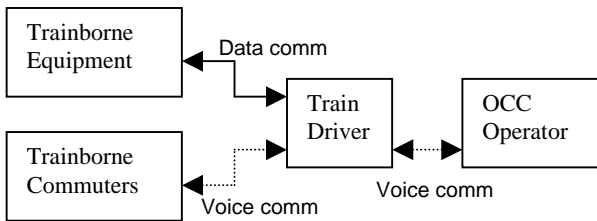


Figure 2 – Communications links for a manually driven train

For a driverless system, information on operating status and alarms of trainborne equipment will have to be transmitted to the distant OCC in a timely manner for the operator to take the appropriate action. This are as shown in Figure 3.

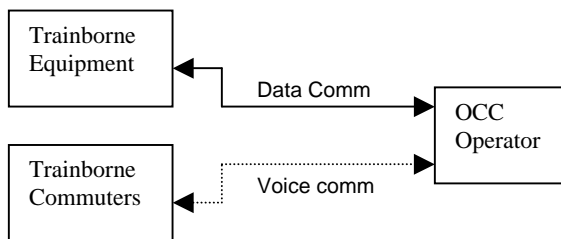


Figure 3 – Communications links in driverless train

Under some circumstances, the operator may have to withdraw the train from revenue service or to evacuate the commuters.

Quite often the same radio communication system used for providing the train voice communication service will also be used for performing remote monitoring of trainborne equipment. Depending on design, the radio system may provide the primary or the secondary (redundant) link for such purpose. Examples of operating status and alarm information that are monitored are alerts on fire/smoke detection on train, malfunction or failure of important equipment such as trainborne signalling, emergency brake, etc.

In addition, OCC operators also make use of the radio system to trigger display of pre-recorded messages, or to send live messages in real time to the information displays installed on the trains. These displays complement the voice services provided through the passenger intercom and public address for normal train operation, as well as during incident management.

Considering the importance of the radio system for driverless transit systems, it should possess the attributes identified below.

Some of these attributes are also applicable to systems with trains operated by drivers, especially for those pertaining to providing voice communication between the train driver and the operation control centre.

2.1 Resilience

As an integral subsystem for driverless operation, the radio communications system must be designed to ensure resiliency that meets demanding availability requirements of 99.99% or better.

System resilience is usually achieved via provision of redundant equipment and hot standby configuration. Malfunction or failure of major radio equipment or its components such as base station controller, radio transceiver, etc. should trigger alarms to alert the operators to take the necessary remedy actions. The RF (radio frequency) communication path should also be constantly monitored for its proper operation. Common ways to achieve this are for the supervisory & control system to regularly poll for the trainborne radio operating status, or to require the trainborne radio equipment to periodically report its operating status to the supervisory & control system.

2.2 Good Voice Quality

The OCC operators rely on the radio system to communicate with the train commuters. Background ambient noise level is expected to be high, be it during normal train service or in the event of an incident.

It is important that the radio system is able to deliver clear and intelligible messages and this is only possible if the required radio signal level is provided.

2.3 Data Communications

In a driverless system, the remote OCC operator takes on some functions that are performed by a train driver in a non-driverless system. The OCC needs to be fully aware of the operating and serviceability status of the various trainborne equipment, more so for the critical ones. OCC operators may also need to remotely control some of the trainborne equipment, such as selection of train borne cameras for viewing, activation of trainborne public address announcements, sending of live text messages to the trainborne information displays, etc. These are realised through the use of radio data communications.

2.4 Simultaneous Voice And Data

While it is important for the radio system to support both voice and data services, it is just as important that these communications can take place simultaneously without affecting each other. As an example, when a commuter is engaged in a conversation with the operator on the voice channel, any critical trainborne alarms should not be lost or delayed in their transmission to the OCC. Conversely any transmission of data signal

should not cause an ongoing voice conversation between a commuter and an operator to be interrupted or dropped.

2.5 Safety Integrity Level (SIL)

In a driverless system, the radio communication system could be the only means for commuters to contact the operator to seek assistance during an emergency. In some designs the radio system may also be the primary communication means for the trainborne equipment to report its operating status to the OCC. Proper safety analyses should therefore be conducted to accord the radio system with an appropriate safety integrity level, taking into consideration the hazards that the radio system helps to mitigate.

2.6 Operation & Maintenance Radio

Quite often a common radio system is implemented on a rapid transit system to provide both the trainborne voice and data communications facilities, as well as used for the O&M radio system due to considerations on cost effectiveness and resource utilisation.

Since the O&M radio system will also play a key supporting function during incident response situation, it should facilitate effective communications amongst the various O&M groups. The O&M radio system should be capable of supporting the various modes and patterns of communications, e.g. individual private (one-to-one) calls and the various modes of group communication, pre-emption based on priority, broadcast calls, etc. commensurate with the specific operating requirements.

2.7 Co-existence With Other Railway Systems

The radio system should co-exist with other railway systems without interfering or being interfered by other radio-based systems. Analyses should be carried out to verify that there will be no interference between radio systems when they are operating simultaneously.

2.8 Good Radio Coverage

Good and consistent trackside radio coverage is key to maintaining radio communication between trainborne radios and the OCC. This may be achieved if the trackside antenna is sited at close proximity, and in constant line of sight with the trainborne radio antenna. Having such arrangement will enhance the robustness of the radio system against interference such as multi-path fading and electromagnetic interference. Close proximity between transmitting and receiving antennae will also help to deal with co-channel

interference. In co-channel interference, the frequency of the interfering signal coincides with those of the desired radio signals, hence filtering cannot be applied to block the interfering signals since this will block the desired signals too.

With close proximity between the transmitter and receiver, FM (frequency modulation) capture effect can be effective in suppressing the interfering signals. The two diagrams below show the installation of leaky coaxial cables (LCX) along elevated viaduct and underground tunnel. The use of trackside/tunnel LCX in these projects ensures good signal coupling and constant line of sight between transmitter and receiver.



Figure 4 – LCX cable on viaduct of Sengkang and Punggol LRT system

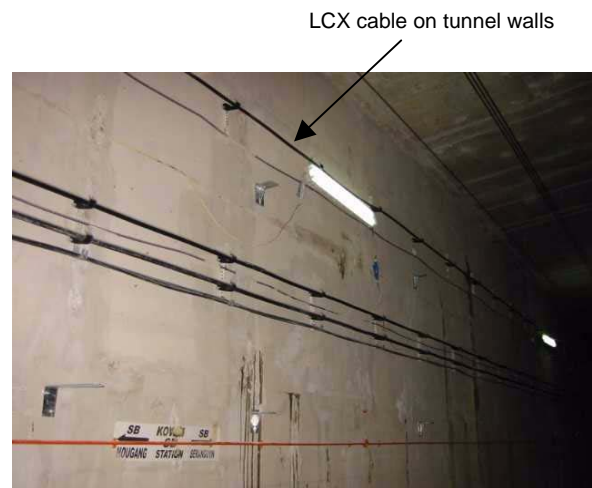


Figure 5 – LCX cables on the tunnel wall of North-South East-West MRT Lines

Where possible antenna diversity design may also be applied to enhance radio signal reception. In antenna diversity design, two or more antennas that are spatially separated by at least a few wavelengths are installed. Such arrangement improves the probability of good signal reception at areas where radio coverage may not be ideal, e.g. in the presence of multi-path interference.

In addition to radio coverage, roaming from one radio cell to another should be seamless without interruption to ongoing radio communications. This may be achieved by ensuring sufficient radio signal level in the time window during which the radio call will be handed over from one cell to another as shown in Fig 6 below.

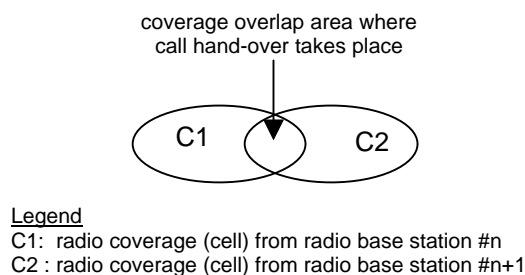


Figure 6 – Call hand-over

3 TETRA

The TETRA (Terrestrial Trunked Radio) is the standard defined by the European Telecommunications Standards Institute (ETSI) for a digital Private Mobile Radio system. Through time division multiple access, each 25kHz RF carrier accommodate up to 4 timeslots. It is therefore spectrum efficient, especially when compared to conventional analogue radio systems. In Singapore, the Infocomm Development Authority of Singapore (IDA) has assigned the band of 380 - 400MHz for operation of TETRA systems.

3.1 Resilience

A TETRA system can be designed to a suitable resiliency level that meets the demanding requirements of a driverless system. Major components of the system can be implemented with redundancy in hot standby configuration. TETRA also provides for fall back mode operation where in the case of major failure of the SwMI (Switching and Management Infrastructure, which typically comprises of the radio switch, data bases, interfacing equipment, etc.) or link disconnection between a radio base station and the main radio switch, the radio base station is still able to continue to function locally. Such a fall back mode feature would allow radio communications within the radio base station coverage areas to continue

normally albeit with some reduction in radio features.

3.2 Voice Quality

In a TETRA system, the voice is digitised using the Adaptive Code Excited Linear Prediction (ACELP) coding. This coding of the speech signal allows TETRA to transmit speech signal at a low bit rate, thereby achieving the spectrum efficiency. It also enables TETRA to provide good speech quality in high background noise environment by filtering out unwanted sound from the high noise environment. Digitisation also means consistent speech quality as only the wanted signal is regenerated. In an analogue system, the noise will be amplified alongside with the wanted signals when the signals pass through amplifiers or repeaters.

3.3 Data Communication

TETRA being a digital system, can accommodate data communications without the need for additional modems. Data communications can be carried out either via control channels in the form of Short Data Services or via traffic channels in the form of packet mode or circuit mode data. External peripheral equipment that uses radio as a communication channel can be interfaced to the TETRA mobile radios using standard-based peripheral equipment interface. Examples of these external peripheral equipment are trainborne CCTV, public address and passenger information systems.

3.4 Simultaneous Voice And Data

In a driverless system, it is important that both voice and data communications can be carried out without affecting each other. In the case of a TETRA system, this can be achieved via a feature known as "Channel Stealing". For example, when a TETRA radio is engaged in an ongoing voice call, the radio continues to send and receive control channel information on the 18th frame of the traffic channel, thus supporting concurrent voice and short data communications in a same radio without the need for additional equipment. This leads to reduction in power supply and equipment space requirements in stations as well as onboard trains.

3.5 Safety Integrity Level

With regards to safety integrity level, radio systems (including TETRA) are usually acquired as a commercial off the shelf product with a certain degree of customisation for integration with other equipment in a railway system. TETRA and most of the other open standard radio systems are generally not developed strictly in accordance with procedure prescribed in SIL standards such as EN

50128. However as a Private Mobile Radio system, TETRA has been successfully deployed in many countries for various applications such as Public Safety, Military, Utilities and Transportation (including driverless Metro systems). Based on information from the official TETRA website, as of August 2005, there are more than 600 TETRA contracts that were let in no fewer than 70 countries. These large numbers of references usually enables a TETRA system to be assessed to a certain SIL level based on actual figures and statistics that were derived from references to similar projects. This is in line with EN50128 standards.

3.6 TETRA Services

The TETRA radio provides a range of inherent features and supports a variety of bearer services as well as teleservices. The inherent features include queuing of radio resource, press to talk handling, secondary common control channels, etc. On bearer (data) services, packet-mode data, circuit-mode data, short data services, single/multi-slot data services are available. On teleservices (voice calls), there are the individual full duplex call, group call, broadcast calls and supplementary services like dynamic group number assignment, patching between talk groups, priority calls, pre-emptive priority calls, etc.

3.7 Co-existence With Other Radio Systems

Finally, TETRA equipment operates in the frequency bands of 380-400 MHz, 410-430 MHz, etc. These frequency bands have been harmonized in various countries, including Singapore for the operation of TETRA system.

3.8 Radio Coverage And Call Handover

In terms of radio coverage, TETRA can be implemented with a cellular architecture with various methods of call hand-over. This architecture is similar to that of a GSM cellular hand phone network where cells of radio coverage are provided by the radio base stations, and calls will be handed from one cell to another as the user roams around within the radio network. This minimises radio blind spots especially at the areas where radio cells overlap, which is quite commonly encountered in a conventional analogue simulcast radio system. When operating out of radio coverage areas, the Direct Mode Operation (DMO) feature of the TETRA provides for direct point to point communications between mobile radios without the need for the radio infrastructure.

4 THE CIRCLE LINE

The Circle Line (CCL) is a driverless MRT system with 29 MRT stations and an underground depot.

The entire line is fully underground and stretches for approximately 33km. Construction is currently in progress and scheduled to be opened in phases.

4.1 The Circle Line Radio System

Radio system in the CCL is implemented using a TETRA system. This selection is made based on consideration of its attributes as mentioned in Section 3.

The TETRA system in CCL is designed for the following applications:

- a. voice communications between passengers onboard trains and the operator;
- b. voice communications among the operators for their operation and maintenance purposes;
- c. selection of closed circuit television cameras on board trains by OCC operators;
- d. broadcast of public address announcements to trains by OCC operators;
- e. transmission of text messages in the train information displays by OCC operators;
- f. downloading of text-based files to passenger information display libraries onboard trains by maintenance staff in the depot;
- g. secondary transmission medium for critical trainborne equipment alarms and status from train to the OCC.

4.2 Configuration Of TETRA In CCL

The TETRA system in CCL is implemented with a radio Switching Management Infrastructure (SwMI) which has a capacity to support up to 64-radio base stations. A radio base station, each equipped with two radio frequency (RF) carriers is installed at each MRT station. In the depot where majority of the trains will stable during the non revenue hour, a radio base station with three RF carriers is installed. Through frequency re-use, a total of seven RF carriers is required for the entire CCL. The deployment of radio base stations and the number of RF carriers at each of the MRT station and depot have been computed taking into consideration the radio traffic requirements along the mainline/depot areas as well as the resiliency of the radio system.

The radio base stations are connected to the radio SwMI which is located at the OCC, via the fibre-optic based communications backbone network. All major modules of the radio base station and

SwMI are designed with redundancy in hot standby configuration. Even on board each passenger train, there are two mobile radios working in hot standby configuration. As for locomotives, hand-portables configured with loudspeakers and microphones will be installed for use by the locomotive drivers.

The architecture of the CCL radio system is as in figure 7.

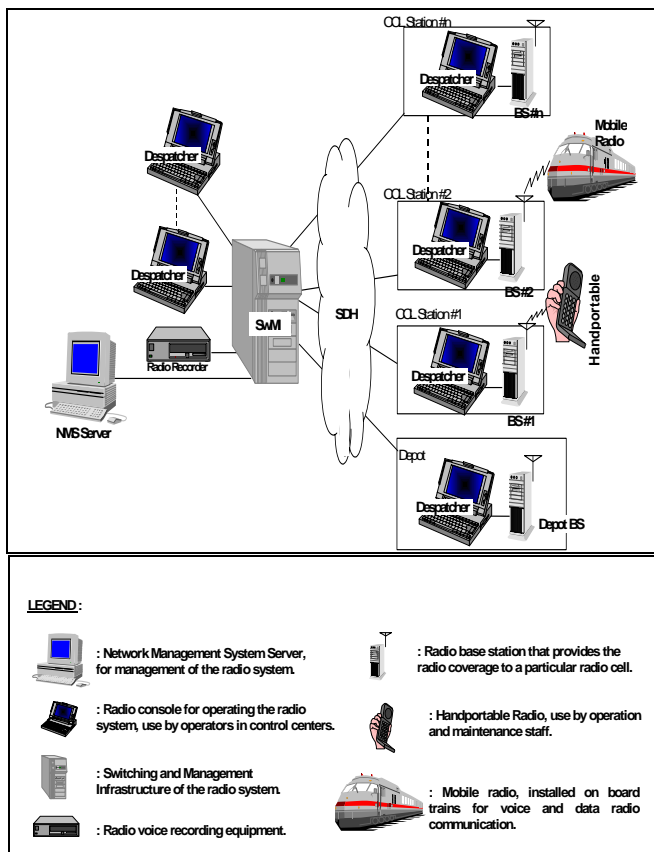


Figure 7 – Architecture of CCL radio system

All the MRT stations in the Circle Line project are fully underground and radio coverage in the tunnels are provided via leaky co-axial cables (LCX). LCX cables are installed on the tunnel wall along the entire length of the Circle Line. This installation of the LCX cables enables train radio and the base stations to maintain continuous line of sight and within close proximity with each other. The close proximity results in low coupling losses between the train radio and the radio base stations, which helps ensure good radio coverage throughout the Circle Line. This is important for achieving good quality speech and data communications as well as seamless handovers between radio cells.

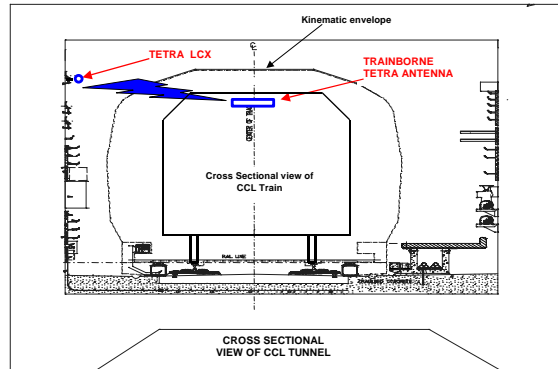


Figure 8 – Position of trainborne antenna and LCX cable on tunnel wall

In the station areas, a mix of LCX cables and indoor antennas provides the radio coverage.



Figure 9 – Position of antenna and LCX cables on the ceiling of a typical MRT station

5 EXPERIENCE FROM THE NORTH EAST LINE RADIO SYSTEM

Singapore's first driverless MRT system, the North East Line (NEL), was opened for revenue service in 2003. It is a fully underground network comprising 16 MRT stations and 1 depot. The NEL and CCL are operated by different operators, and each line has its own TETRA network.

The development of the Circle Line (CCL) radio communication system did overlap with the NEL project testing and commissioning phase. Lessons learnt from the NEL project have been applied to the CCL where possible. These lessons learnt are especially valuable and relevant since both lines employ the same TETRA system and have similar system architecture.

However there are also differences in the two systems, e.g. in terms of system capacity and provisions since the CCL is a larger system. Newer model equipment with richer features is also supplied to the CCL.

Experiences gained from the NEL are briefly described in the sub sections below.

5.1 Design On Resilience

In NEL trains, Trainborne Computer Interface (TCI) is implemented and supplied by the communication system contractor for the purpose of providing switching control, diagnostics and alarm reporting functions for the trainborne communication systems. It provides audio and data interfaces to the trainborne TETRA radio, train data management system (TDMS), train information management system (TIMS) and trainborne CCTV controller. In terms of configuration, the TCI is the "master" controller for the TIMS interface, but it is also the "slave" for the TDMS interface. The design is further complicated by the redundant control interfaces between the various equipment which requires significant amount of integration and interfacing effort to ensure synchronisation and reliable switch over operations.

It is desirable to reduce the number of interfaces so as to simplify data exchange and redundancy switching design. The CCL takes this into consideration and the function of the TCI is transferred to the TIMS. The removal of the intermediary interface will also help in the trouble-shooting. All these should improve the overall resilience of the system.

5.2 Radio Coverage

In NEL, the tunnel LCX cables are designed to be continuous and radio signals from one radio base station would propagate along the LCX for longer distance in comparison to a LCX that is terminated. This means that for stations with short tunnel length, the same frequency can not be re-used at every alternate radio base station and further physical separation is required. In CCL, attenuators are inserted in the LCX joins in the mid tunnel areas. This facilitate tuning of the radio signal strength for better control of signal propagation and call hand over design between radio cells.

5.3 Data Communications

Based on experience from the NEL, the packet data size adopted in the CCL radio system design is optimised for transmission over the TETRA Short Data Service . This ensures that the SDS is not overloaded to cause voice calls to drop.

5.4 Interfaces With Other Systems

Experience from the NEL shows that for such highly integrated system, interfaces between systems, information exchange, alarm management, redundancy switching, etc. should be clearly defined for various operating scenarios. These have been addressed in the CCL design and as far as possible interfacing parameters are mutually agreed between the interfacing parties.

The amount of data transfer between radio system and others such as the Integrated Supervisory Control System is also reduced where possible so as to avoid overwhelming of data flow, causing systems to "hang" and malfunction.

5.5 Operations

Basing on feedback from NEL operation, flexibility has been introduced to the CCL to allow operators at the OCC to be able to log on to different operating consoles while maintaining their specific roles and functions affiliated to them for operating the transit line.

5.6 Electromagnetic Compatibility

Antenna infrastructures for CCL has been designed and selected such that electromagnetic compatibility (EMC) both within the CCL project (intra-system EMC) as well as with the environment (inter-system EMC) is minimized.

6 CONCLUSION

With the high degree of integration and automation in driverless rapid transit systems, it is essential to have a radio system that is reliable and efficient in supporting both voice and data communications simultaneously.

The requirements of radio system for a driverless system have been considered for Singapore's rapid transit system and it has been assessed that TETRA is a suitable technology to be applied. TETRA system has been successfully employed for the NEL and it will also be implemented for the CCL, as well as future driverless rapid transit systems.