MAHSR Project

Vignesh S

EE16B127

Guide : Prof. R David Koilpillai

Department of Electrical Engineering

Survey Report

Signalling in High Speed Rail

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1 Abstract

This project focuses on the Signalling aspects involved in High Speed Rail with the goal being able to incorporate this study to help the Mumbai - Ahmedabad High Speed Rail (MAHSR) project. Initially a brief overview of the different High Speed train systems used around the world is seen and then it dives a little deeper into the system(its sub-systems) that would be incorporated by the MAHSR project. Then it moves onto the train-to-wayside communication, which is very crucial in ensuring the safety of the HSR system. A brief discussion will then be done about one of the techniques used for the above purpose, which is the Leaky Coaxial Cable(LCX) and how it can be implemented. Finally, a small overview is done on how information about the train, communication etc. can be provided to passengers on-board in the High Speed Rail.

***KeyWords* :** train-to-wayside communication, ATC, LCX, LWG

2 Introduction

With increasing traffic not only in the ground, but also in the air, few solutions are left to reduce the transportation time in these days. One of the things that is on the mind of anyone ardently looking for a solution to this issue is the High Speed Rail(HSR). Though the idea is not a new one, the development in this field has been rapid to say the least. A large part of this credit can be given to the steady progress in the field of communication, which is one of the key elements in a successful and efficient HSR system. The typical speed of these HSR trains are around 200km/h and it is not possible to expect humans to control these systems directly(such as being a driver etc.) since even a small human error can cause devastating effects. Hence one can see why Signalling forms one of the major parts of a HSR systems, for both its safety and efficient functioning.

3 Different signalling systems and their sub-divisions

3.1 Signalling systems

Some of the popular HSR systems around the world and the their signalling ATP(Automatic Train Protection) systems are

Region/Organization	Signalling (ATP) system
Japan	Digital-ATC(Automatic train control)
European Rail Traffic Management System	ETCS(European Train Control System) Level-2
China	CTCS(Chinese Train Control System) Level-3
France	TVM(Transmission Voie-Machine)-430
Geramny	LZB(Linienzugbeeinflussung)

Among these the ones that are usually followed as model are ETCS or the Digital-ATC. Given below is comparison between the two, obtained from the Feasibility Reports of NHSRCL[1]

Table 9.11-2 Comparison between Digital-ATC and ETCS Level-2

	Digital-ATC	ETCS Level-2
Safety Integrity Level	SIL-4	SIL-4
Block system	Fixed block	Fixed block
Type of signalling	Cab signalling	Cab signalling
Method for track occupancy detection	Track circuit (AFTC (Audio Frequency Track Circuit))	Track circuit (AFTC) or axle counter, etc.
Transmission method of MA	Rail	GSM-R
Braking Pattern	Retrieval of single-step braking pattern	Calculation by on-board device
Deceleration Control	Smooth automatic braking when trains stop at stations	Automatic braking when trains stop at stations
Running distance when train stops	As same as ETCS L-2	As same as Digital-ATC
Line Capacity on new constructed project	As same as ETCS L-2	As same as Digital-ATC
New installation	A few number of equipment -ATC & Interlocking device -Track Circuit -Fixed balises	-Radio Block Centre (RBC) -GSM-R network (MSC and BTS, etc.) -Interlocking -Device for track occupancy detection -Fixed balises
In operation as of 2013	2,182km	2,281km
Comparison of cost	As same as ETCS L-2	As same as Digital-ATC

Though each of them have their own advantages and disadvantages the MAHSR team have chosen the Digital-ATC system over the ETCS and following are some of the main reasons stated by them in the report [1]:

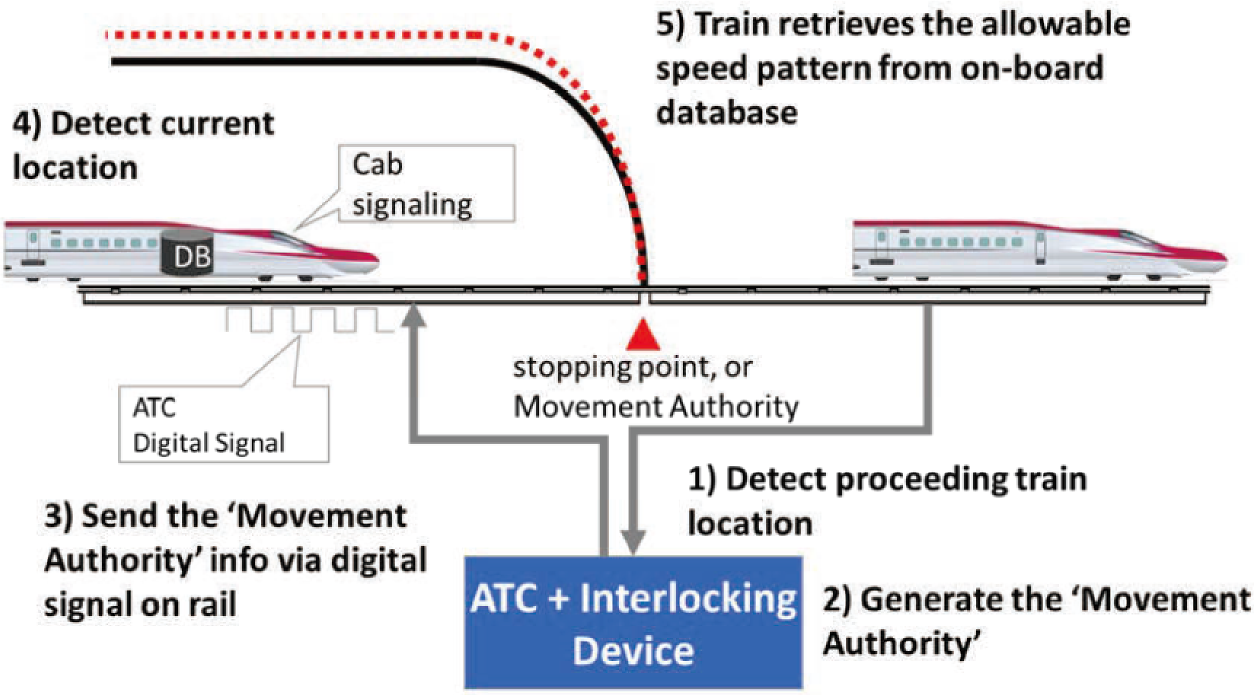
- Digital-ATC has less equipment than ETCS Level-2, which reduces maintenance cost.
- Digital-ATC has brake pattern stored on high-speed trains, so response time is fast.
- Digital-ATC has higher safety, availability and reliability.
- In ETCS Level-2, GSM-R network is necessary to be installed as a subsystem of ETCS Level-2. However, Indian Railways GSM-R frequency band allotted is now only 1.6MHz (952.8-954.4/907.8-909.4MHz), which is not sufficient to control high-speed trains.

3.2 Sub-systems of Signalling

Above we saw the different ATP systems, their benefits etc., but it is not the only thing that the Signalling comprises of. We emphasize in this section the importance of efficient communication between the train, wayside and Operation Control Center(OCC). Given below is a brief description of some of the main sub-systems that are necessary to have the required signalling :

Automatic Train Protection (ATP) system

The ATP systems are categorized based on the functionality and Transmission, among which the Digital-ATC system falls under the continuous system with dynamic speed profile. The braking of a HSR train using ATC is shown in the picture[1] below :



As observed above the train transmits its current location which is gathered by the communication setup near the wayside(near the rail) and this is then sent to the OCC, which in turn generates the 'Movement Authority'(the speed limits along different parts if the track etc.) and sends it back onto the rail setup. Based on what is received from the rail, the train on-board system makes a decision on the speed, acceleration etc. Thus the above example illustrates the need for efficient communication between train and the rail setup.

Some of ATC's ground equipment functions involve detection of train, preparation of track circuit information (as to train should stop), preparation of information for temporary speed limit, telegraphic message transmission etc. Some of the ATC's on-board functions are Position recognition, Speed check patterns(involving Normal and Emergency Brake pattern[1]), Speed indication and limit etc. In case equipment for Digital-ATC fails and becomes unavailable, the Fall-Back Block system can temporarily be worked to maintain safety and smooth operation.

Interlocking device and Track Vacancy Detection system(ATFC)

Interlocking(Electronic Interlocking or EI which is used here) is a device that is used for Route setting for safe movement of trains, to control point machines and track circuits etc. The system will automatically make train routes based on train diagram and route data stored in a station device for route controller. Daily train diagram and route data are periodically transmitted before the operation day from operation control system in OCC via telecommunication network. Audio Frequency Track Circuits(AFTC) are used for detecting train vacancy. The signal level adjustment function of the AFTC device automatically changes the boarder of occupancy track or vacant.

Systems to realize 'Fail-safe' operation

This is forms an essential unit of the Signalling system by acting as a feedback and provides the required stability. Some of the functions include, detecting Inter-system fault(can initiate the emergency stop signal), functions along with the Interlocking device to prevent collision with High Speed trains(In case of stoppage of some trains, informs the Interlocking to change the route of the other HSR trains), prevent collisions with conventional cars or vehicles (by using the optical cable laid on the fence) etc.

These are just a few of the sub-systems that Signalling is comprised of. But from the working of these the importance of communication between HSR train and the Operation Control Center(OCC) (which happens via the wayside setup) can be assimilated.

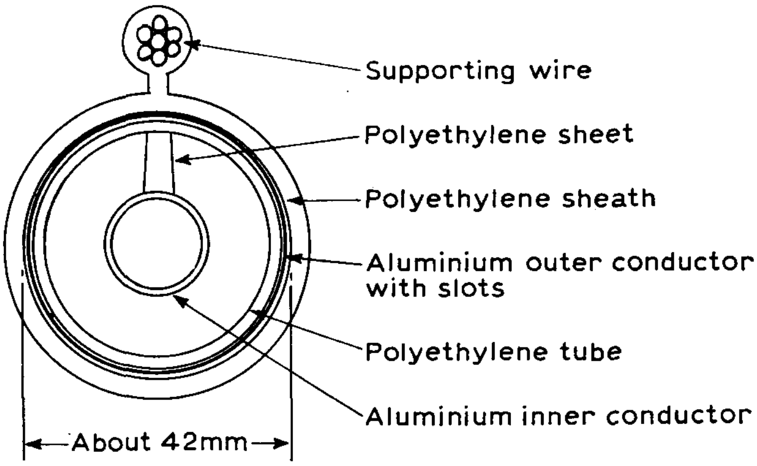


Figure 1: Structure of LCX

4 Analysis of Leaky Co-axial Cable(LCX)

4.1 LCX : Definition and purpose of usage

LCX are just as the name suggests, coaxial cables but leaky, or in formal terms, it is an adaptation of the standard coaxial cable wherein the outer conductor is punctured with slots periodically. This leaks the electromagnetic waves confined in the coaxial cable(which defeats the purpose of restricting the EM waves) but if the slots are shaped and positioned in a particular manner they provide good characteristics to act as antennas for mobile connectivity etc. in confined regions such as tunnels, underground facilities , airplanes etc. They are strong, flexible and robust against environmental conditions. In the radiated mode, LCX effectively acts as an array of broadband antennas with a number of radiating slots along its length[2]. Fig 1 depicts the structure of a LCX

As we saw in the previous section it was very much essential to have a good train-to-wayside communication to ensure safe and optimal working of the Signalling system. As we know due to several constraints(public safety, lack of space etc) it is not possible to have HSR systems in open city area, hence these are constructed in subways and underground tunnels. But the problem with this is finding a good means of communication between HSR train, OCC and wayside setup. Though in these confined areas natural propagation(using antennas and

Access Points(APs)) works, LCX has some advantages of its own. Over the required communication ranges of several hundred meters, between stations, such LCXs provide low longitudinal attenuation and remain of reasonable size. They also provide predictable communication ranges that could offer significant advantages over the natural propagation approach[3].

4.2 LCX : Characteristics and Working

The important characteristics of LCX are low transmission and coupling loss. They are defined as follows[4],

Transmission(Tx) loss : A 50m LCX is inserted into a concrete floor and the insertion loss characterized over 1km is known as Tx loss.

Coupling loss : A half wavelength dipole(with a Rx antenna) placed 1.5m above the LCX and the LCX ends are connected by dummy load on one side and Tx antenna on the other. The difference between transmitted power and the received power in dB is the Coupling loss. It's done across the full length and average coupling loss is obtained.The loss(transmission loss and coupling loss) due to rain and snow is negligible at 400MHz(usually at which its operated)

The following table shows different types of LCX and their Tx and Coupling losses[4]. It should be stated that the LCX which have low Coupling losses are ones which get easily affected by external factors, hence 45 type is used in the later experiments.

Type	Coupling loss(dB)	Tx loss(dB/km)
45	50	36
46	55	26
47	65	23
48	75	23

A LCX has to be placed above a concrete wall and hence it is important to know the effect the wall has on the Tx and Coupling loss. From the experiments conducted(standards of Japanese National Railway(JNR) are used, eg. frequency of operation is around 400MHz) and using the theory known to explain these observations [4], following conclusions have been drawn, The Tx loss is inversely proportional to the distance from the concrete wall(h). The coupling loss varies

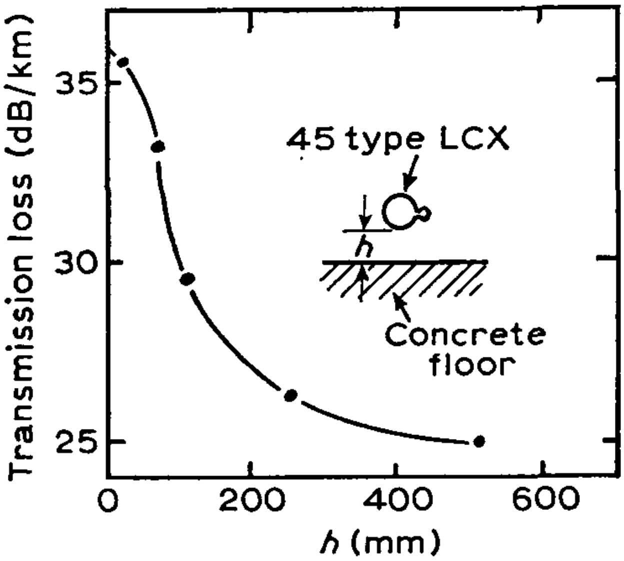


Figure 2: Transmission loss versus distance between concrete floor for 45 type LCX

periodically around 9 to 10 dB with respect to h. These conclusions can be more clearly seen by the Fig 2 and 3 below (The relative Electric field strength gives a measure of the coupling loss observed.),

There are 4 different orientations(widely used) in which a LCX can be placed around a concrete wall. The fig 4 and table below [4] shows the properties of different orientations,

Orientation	Coupling loss	Fluctuation
Above the wall	worst(maximum)	worst
In the pipe	bad	good
On the wall	good	bad
Beside the wall	best(minimum)	best

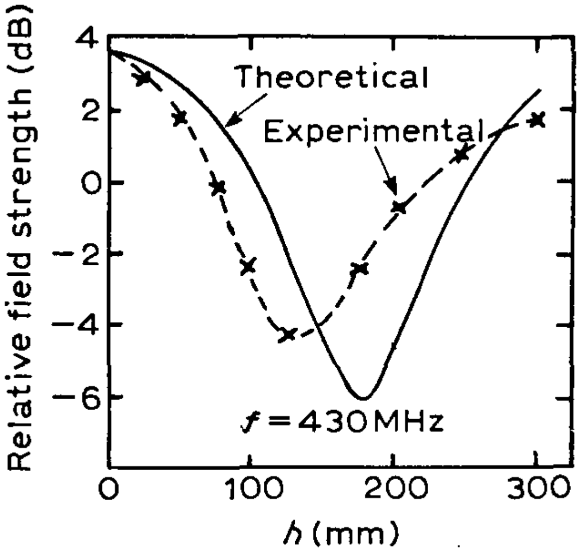


Figure 3: Relative strength versus distance between concrete floor for LCX

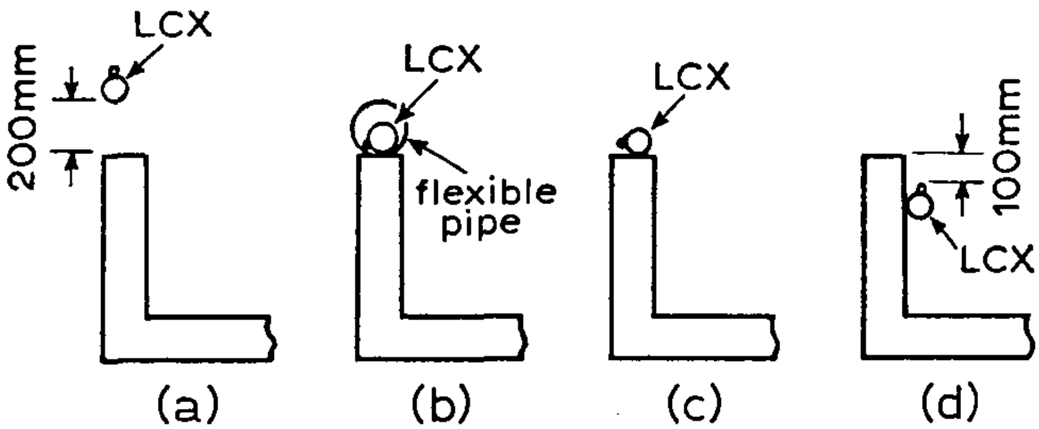


Figure 4: Positions of cables installed in the experiment :
(a)Above the wall (b) In the pipe
(c) On the wall (d) Beside the wall

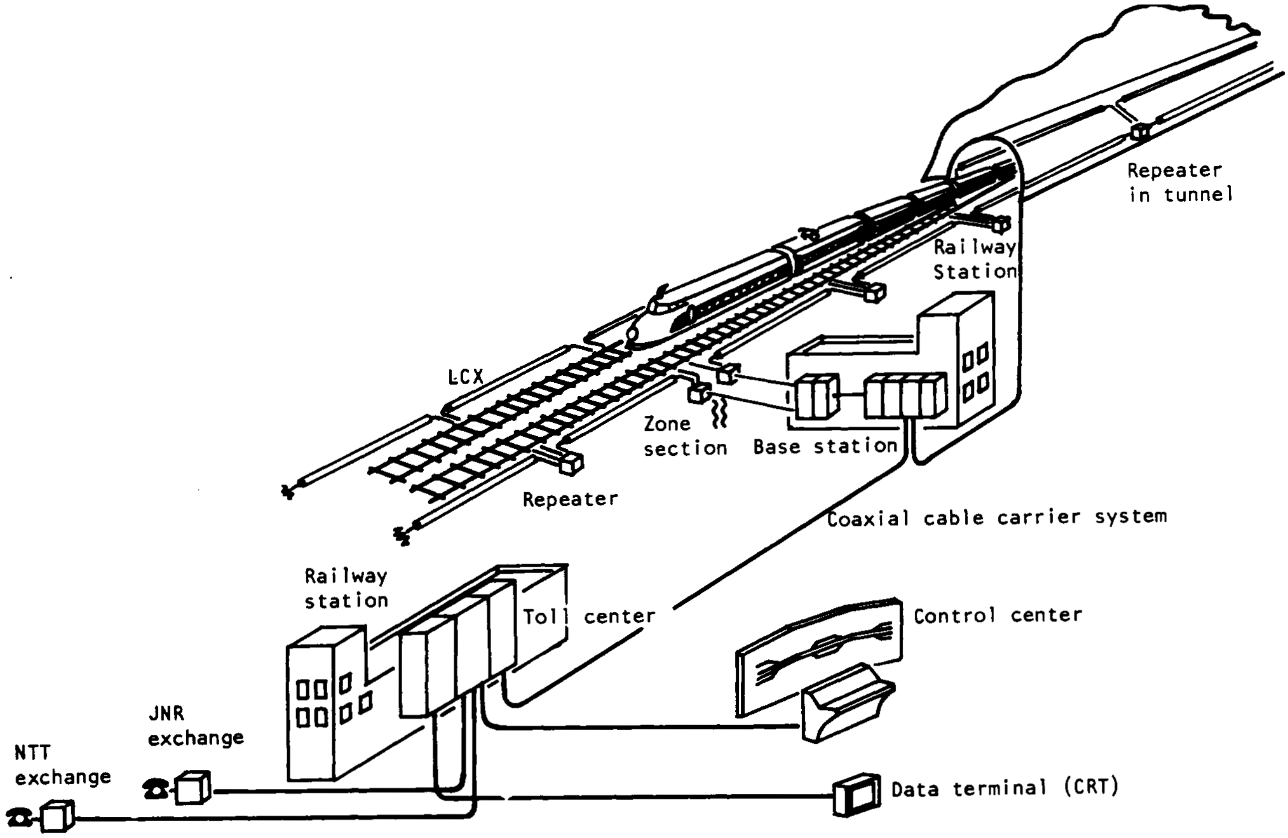


Figure 5: Train radio system

4.3 LCX : Implementation

Observations and conclusions in this section are drawn based on the some of the research done[5] on the Japanese National Railways(JNR) which uses LCX. This system is designed to have 40dB SNR in almost 99 % of the areas (voice communication channels) and less than 10^{-4} BER for 1200 bits/s FSK (data communication channel) in most areas. Their LCX system is mainly used for the following purposes, Train operation dispatching(HSR train to OCC communication),Passenger dispatching(provision for information to passengers), Public Telephone(to make phone calls) and Data Transmission(train status monitoring) etc. Given in Fig 5 is a simple sketch[5] which outlines the working of the train radio system.

Using Fig 5 as reference, it can observed that LCX, which is connected serially on both sides of the track, along the railway line transmits a radio signal and exchanges it with the mobile antenna present on the HSR train. Direct amplification repeaters are placed every 1.5km and a base station which is usually

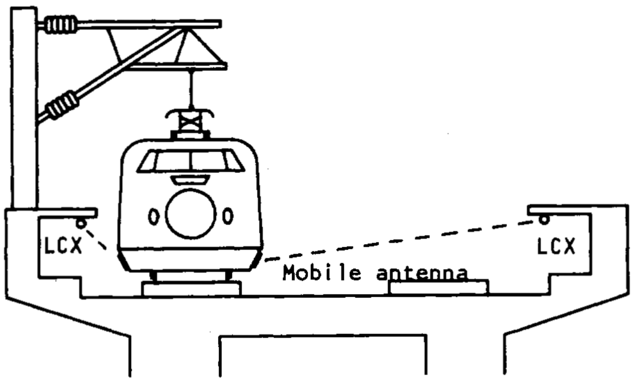


Figure 6: Inverted L structure

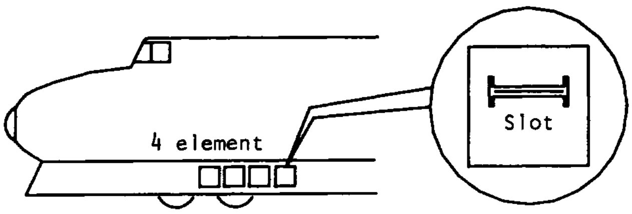


Figure 7: Slot array antennas

located in a railway station is connected to the toll center through a coaxial cable carrier system. The toll center covers several base stations and thereby controls and distributes command and data to the appropriate places.

The LCX used here is similar to the standard one, except this has zig-zag slots which suppresses the surface wave interference. The train has slot array antennas as shown in the fig 7. This has a matched directivity with the LCX which also radiates in a particular angle. To ensure its beside the wall(which is the efficient orientation as seen above) and does not get affected by snow etc. the LCX is placed in an inverted L shape. It can be seen that if there is only one train on the track then both the LCX will help in communication of information from train-to-wayside. Apart from this the transmission from base station to mobile happens through multiplexing of 24 voice channels over a frequency(since base station have identification signal) whereas mobile to base station happens through 24 regularly allocated Single Channel Per Carrier(SCPC) with 25kHz spacing.

Data transmission can happen through the train radio system, wherein we

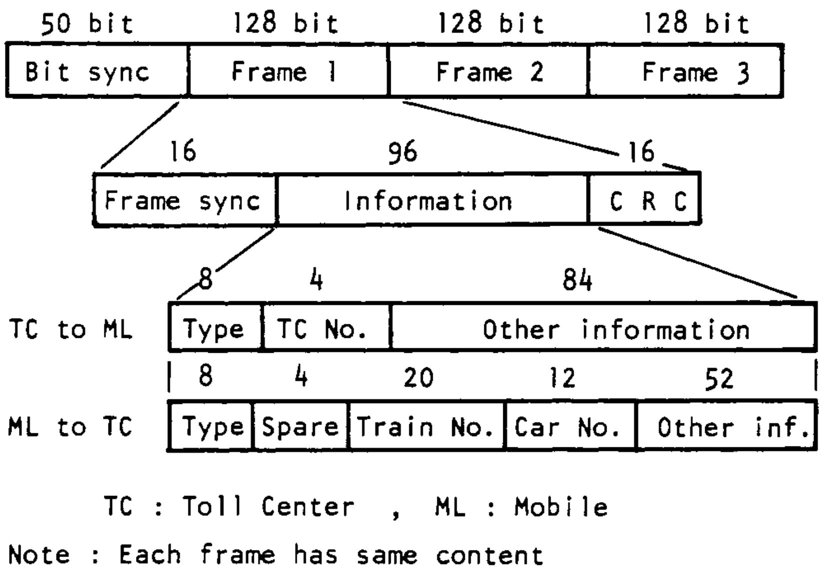


Figure 8: Data Block transmitted

can transmit train location data, spot calling using the public phone etc. The transmitted data format is as shown in fig 8 [5] . There is 1 data block which has 3 frames each containing the same information. At the receiving end majority rule is used to determine each bit of the frame(similar to repetition scheme). After this, the frame is CRC(cyclic redundancy check) checked and the information is obtained. This gives a block error rate less than 10^{-3}. A particular example of the set of information that can be transmitted is given below. As it can be seen this method is inefficient. Another method namely Simple Automatic Repeat Request(ARQ) is used which uses only 1 frame of data, but involves decoding using CRC and other complex methods. The ARQ is not as reliable as the triple transmission method, hence is usually restrained form usage.

The bit error rate(BER) for mobile channels may vary from point to point, but overall the system is expected to keep BER below 10^{-4} in almost all areas. An experiment conducted[5] (results shown in Fig9) shows the BER at different points along the train, when 10000 bits were transmitted simultaneously. A detailed analysis showed that apart from the zone sections everywhere else, the BER was below 10^{-4}.

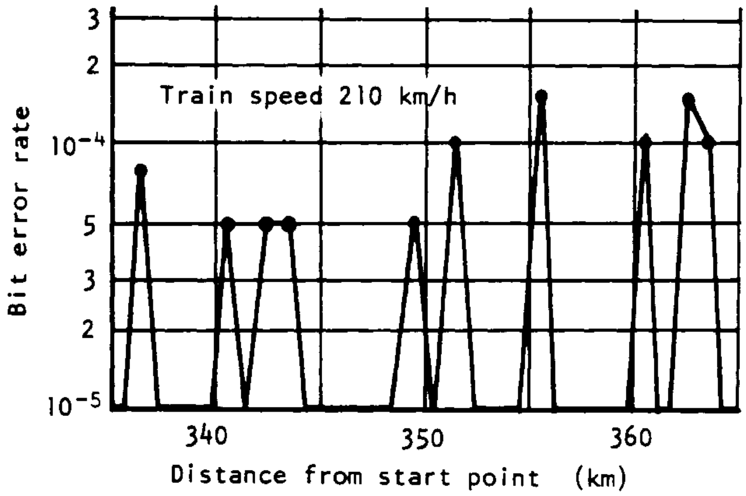


Figure 9: BER along the train

4.4 Propagation characteristics of Leaky Waveguides(LWG)

At frequencies below 1GHz LCX act as continuous radiating structures. As seen above the widely used frequency range for railways is 450-800MHz. But above 1GHz the longitudinal attenuation becomes significant (of the order of 80dB/km). Hence to overcome this a the dielectric of the LCX is removed and an empty waveguide is used, which provides considerably less attenuation at a reasonable size. This in a way provides a certain similarity between the LCX operating at 400MHz range and LWG operating at GHz range, and since it is easier to perform tests at higher frequencies(we have higher data rates) comparisons can be drawn in the tests performed on LWG and can be indirectly used to explain propagation characteristics etc. of LCX.

An experiment[3] is done in a tunnel, to find its propagation characteristics and for this its assumed that the tunnel is an oversized waveguide, since wavelength(in cm) is much smaller than the transversal dimensions. With this assumption, the propagation becomes similar to multi-path channel with white Gaussian noise. The below equation gives solution to the deterministic model.

$$h(\tau) = \sum_{k=0}^{N-1} a_k \delta(\tau - \tau_k) e^{j\theta_k}$$

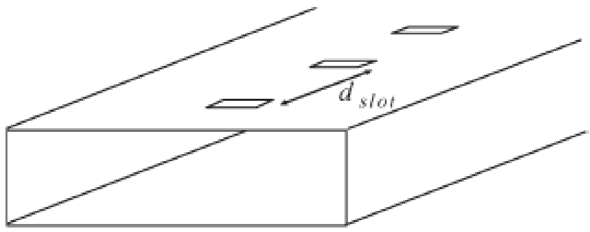


Figure 10: Rectangular Slots along the LWG

The experiments [3]were conducted in a 8m wide 6m high long tunnel, to understand the propagation along the LWG . One of the standard ways of communication ,also called natural propagation,(in a tunnel without using LWG) between train and wayside, is to keep 1 or 2 antennas on the extremities of the train and have Access Points(APs) every 400m. But this might not work all the time, for example if there are multiple trains which can block each others path, then the signal strength might go below the required SNR, which is not a sign of good design. A LWG with slots(rectangular) very small compared to the length of the entire LWG(shown in the fig 10) is employed and is placed at different parts of the track. Consider 2 LWGs each of length 40m kept at a height 30cm above the ground and 2m away from the side of the wall, one placed from 20m to 60m along the track and another from 110m to 150m. A 0dBm 2.4GHz source is used and the receive antenna is placed at 30cm above the LWG and the power is observed and plotted which is shown in the fig 11[3] below,

We observe a clear rise in the power level at around 20m and 110m indicating the LWG radiating. But the drop in power is slightly less steeper and this can be attributed to the fact that the slots are directional(here in the direction of the far side hence having a little influence). Now further experiments[3] were done using both LWG and the APs with only 1 antenna. A LWG is placed from 20m to 100m and the main antenna is at the front end of the train near the AP. If there was no LWG then it would been a decaying curve form 400m to 1m. But now, since there is a LWG at the beginning, it pushes the received signal power to around -60dBm and after that the signal received from AP combined with the

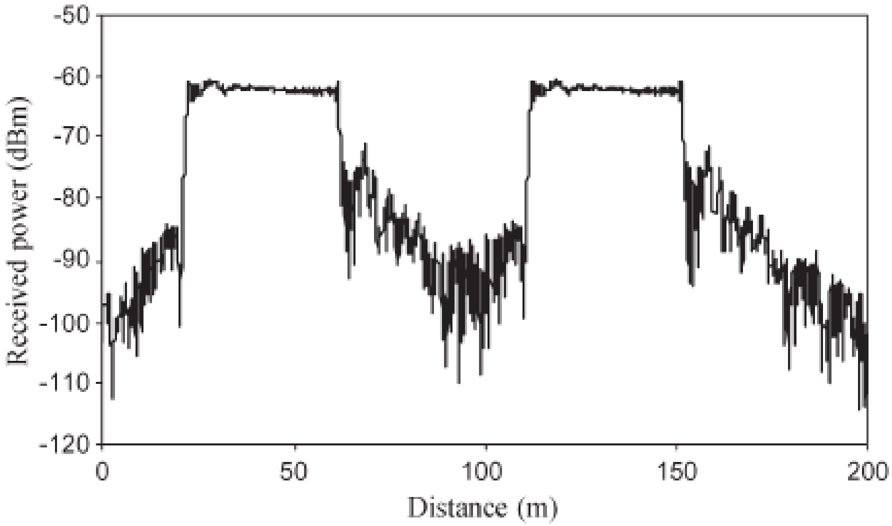


Figure 11: Power received(dBm) vs Distance along the tunnel without APs

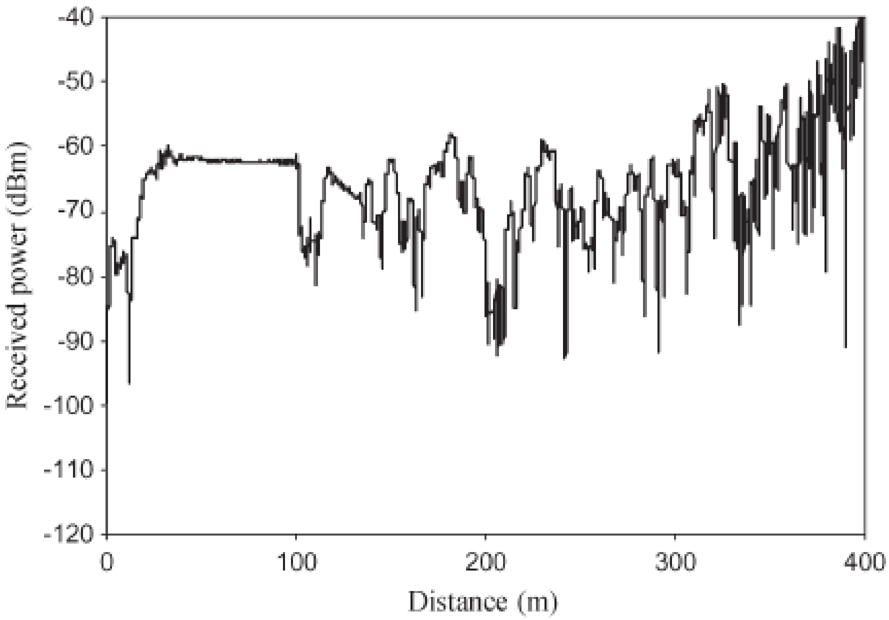


Figure 12: Power received(dBm) vs Distance along the tunnel with APs

Figure 13: Setup of the experiment

partial strength from LWG, the received power remains over -60dBm at all times. This is shown in the Fig 12[3]

There are several other examples mentioned in [3] another important one being an experiment where only 1 LWG is kept inside the tunnel, the receiver is placed at different heights and measurements are taken and it was observed that as the height increased, not only did the received power decrease but also it became harder to distinguish the start and end points of LWG. Fig 13[3] shows the setup used for the experiments.

So from all these experiments and study of characteristics of LCX and LWG, it was possible to get an idea on the importance of these in HSR projects.

5 Information transmission to passengers

5.1 Methods used to transmit information

To have good communication facilities for passengers in the train it's important to have high data rates(or higher bandwidth allocation). But the conventional system used in Japan has only a speed of 9.6kbps. The LCX provides a speed of 384kbps,which is used efficiently for many purposes like public phone calls, train status data transmission etc. But this does not provide much help to the On-board passengers to enjoy good connectivity of data. There are Broadband radio systems like WiFi(20Mbps speed) and WiMAX(40Mbps speed) which offer better solution to this problem. But they involve their own infrastructure. There are some solutions which involve using both WiFi/WiMAX amd LCX which has a lesser budget constraint(mentioned in [7]) and further research is being done on the same.

5.2 SDN based approach for WiFi in Rails

This discussion and analysis is completely based on the research done on WiFi in Rails in [6]. The system used in [6] works on a hand over mechanism, but uses a modified version of it. Each train has a minimum of 3 roof top antennas that receive and transmit signals to the Pole Access Points (PAPs). The PAPs are placed in such a way so that at least one of the 3 roof top antennas are connected to them at all times, sometimes more than that depending on the location of the train. The distance between the PAPs is around 650m, but this just an example considered and the distance can be chosen based on convenience. The whole system has 3 levels of architecture ,

Inside the train : Here there is a train gateway and a control unit along with 3(or more) antennas inside the train that allow devices to connect to them and ensure the WiFi is provided.

Major Stations : Here there are units called Station control and Station Gateway that take information form the PAPs and keep track of which train is running and the IP and MAC addresses etc. Each Major station has a set of PAPs that come under its surveillance. It keeps track of the train details until the train is connected to any of its PAPs.

Core Network : Again this also has core control and core network and these get information from the Station gateways. They keep a track of the train from the beginning till the journey ends.
It has mobility mechanism for how the system works from beginning to end of journey, which has the following 5 steps, a)Initial configuration b)TCEIDP(Train Connection Establishment and Information Dissemination Protocol) c)Tracking connection status d)Packet traversal throughout the system e)send NAT entries

There are some simulations done for different speeds, but they are not completely accurate since the channel conditions have not been considered at these high speeds.

6 Feasibility research on LCX

To establish communication using the LCX it is key to understand the characteristics and model them. The frequency range at which the LCX must be operated is given below as mentioned in [8]

$$\frac{c}{d(\sqrt{\epsilon_r}+1)} < f < \frac{c}{d(\sqrt{\epsilon_r}-1)} \tag{1}$$

where f - frequency of operation, c - speed of light, d - periodic slot interval d and ϵ_r - relative permeability of the dielectric The coupling loss(L_X) of the LCX can be formulated from experiments as,

$$\begin{gathered} L_X = P_t - P_r - \alpha x \\ \alpha = \alpha_1\sqrt{f} + \alpha_2 f + \alpha_R \end{gathered} \tag{2}$$

where P_t : Input power, P_r : power at antenna, x : Distance from i/p end, α : Tx loss coefficient, α_1 : Conduction loss coefficient, α_2 : Dielectric loss coefficient, α_3 : Radiation loss coefficient
Consider the experimental setup as mentioned in [8], with 2.4GHz applied to the i/p end of the LCX. The receiver power was measured for every 100m of the propagation distance. The results emulate the theory and provide an almost linear curve between the Rx power and propagation distance. The slope of this curve gives the Tx loss coefficient. The plot of experimental data is shown below

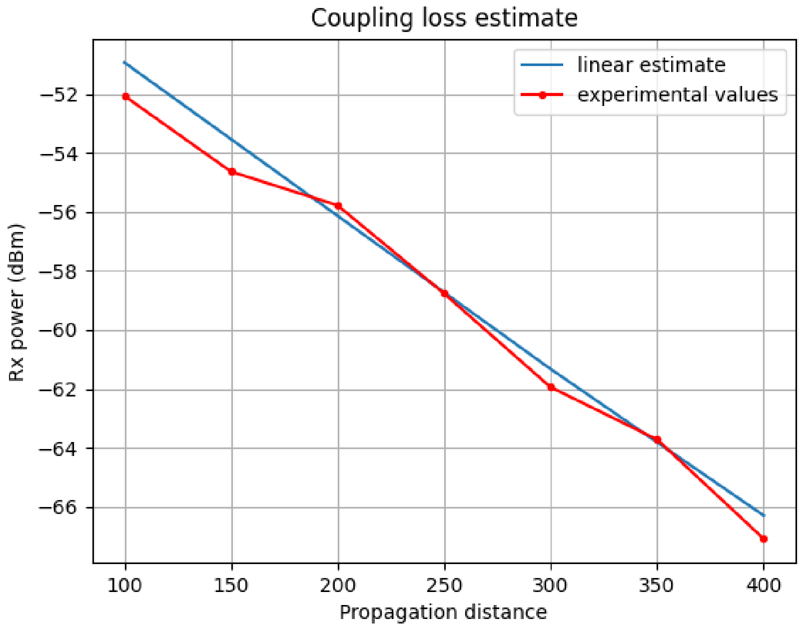


Figure 14: Setup of the experiment

From the graph it can be estimated that there is an average attenuation of 5.5 dBm/100m and the slope is approximately 0.055 dBm/m. This slope value is very close to the variation of coupling loss which is around 0.058 dBm/m. In urban areas the Access Points are present every 300m, but as can be seen from the graph, the LCX can handle power requirements upto 400m (if the threshold is around -70dBm)

7 Conclusion

From the above made discussion, it can be seen that the Japanese model of Digital-ATC is much suited for the MAHSR project. The LCX system which also used in Japan's high speed rail, has a lot of advantages over the traditional natural propagation and can be adapted according to our demands by using appropriate length, positioning and also shape and size of the slots. There is much more scope for the development of WiFi and WiMax methods that will be used to allow people enjoy efficient communication in the near future. Thus it can be seen that HSR projects are an important solution to the transportation issues and that further research that has to be done in this field in the upcoming years.

8 References

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