Radio Propagation Measurement of Subway Tunnel for CBTC Systems

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Abstract **– In order to design wireless communication systems for CBTC use in subways, radio propagation characteristics inside tunnels are important. This paper describes 2.5 GHz and 5.7 GHz propagation loss measurements using dipole and patch antennas in a 1200 m section of a newly constructed tunnel which included some slopes and curves. Line-of-sight between transmitter and receiver does not exist after 180 m and reflections from the wall surface are the main propagation mechanism. The attenuation constant of propagation loss in the non line-of-sight region ranges from 0.026 to 0.03 dB/m.**

Index Terms **— Radio propagation, tunnel propagation, non line-of-sight, CBTC.**

1. Introduction

Communications-Based Train Control (CBTC) systems using wireless communications are put into practical use in railway networks [1]. Many CBTC lines apply Wi-Fi technology and can cause interference with Wi-Fi communications used by passengers. For large amount of interference, there is concern that the link budget does not properly take into account this large interference margin. To design the appropriate link budget, it is therefore necessary to understand the propagation environment.

In China, public transport investment in subway construction is flourishing. Empirical equations to solve for the propagation loss are a fast way to estimate the communication coverage. Based on [2], existing empirical equations are for straight tunnels. Unfortunately these equations are not applicable for long tunnels with curves and slopes. This paper reports the propagation loss processed from measurements made inside a subway tunnel with curves and slopes using 2 kinds of antennas at 2 frequencies.

2. On-Site Measurements

Radio propagation measurements were conducted at 2.5 GHz and 5.7 GHz inside a 1200 m section of a subway tunnel in Harbin city, China. The tunnel included slopes and curves, and still does not include railway tracks and other facilities as shown in Fig. 1. There was still no air conditioning, so the temperature was about 10° Celsius with 100% humidity. The measurement location is part of a new line of the Harbin Metro. For transmitter (Tx) and receiver (Rx) distances larger than 180 m, the propagation environment is non line-of-sight (NLoS).

(1) Measurement Method

Received power was measured with a real-time spectrum analyzer as shown in Fig. 2. Data is acquired via USB using the streaming record function. Tx and Rx were located at the center of the tunnel's cross section, and the heights set at 3 m. Tx and Rx antennas are either both dipole or patch antennas with vertical polarization. At every 100 m, a marker was placed to indicate the exact position for off-line processing.

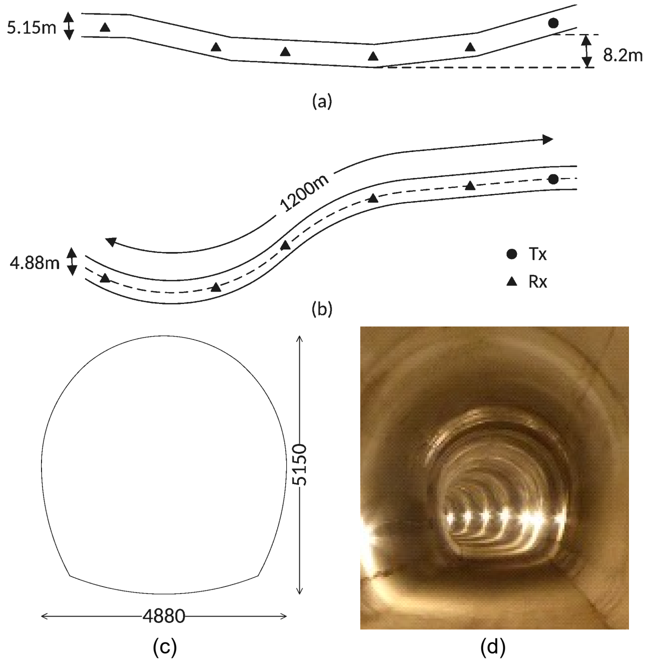

Fig. 1. The tunnel (a) side view, (b) top view, (c) cross section in mm and (d) measurement site.

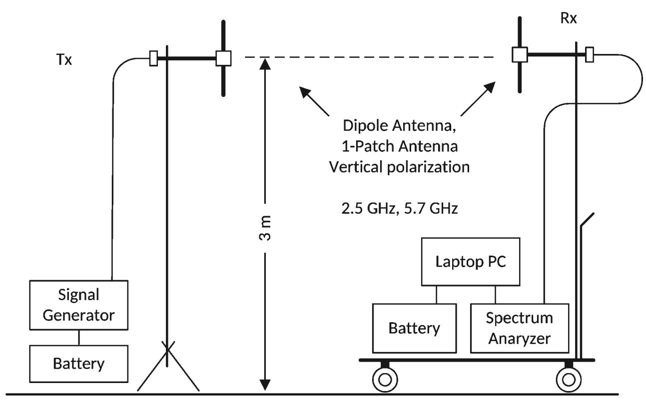

Fig. 2. Measuring equipment composition.

(2) Measurement Results

The acquired instantaneous received power data is first converted into IQ data. Then FFT with 20 ms resolution is applied to get the magnitude of the desired frequency. The transmit power of 10 dBm and maximum gains of the corresponding antennas are then deducted to get the instantaneous propagation loss versus the distance travelled from Tx as shown in Figs. 3 and 4, for 2.5 GHz and 5.7 GHz respectively. The moving median using 100 wavelengths taken from the instantaneous value is also plotted. The top figures of Figs. 3 and 4 show results when dipole antennas are used, while the lower figures show results when patch antennas are used.

The results using dipole antennas show more fluctuations than the patch antenna results. This is due maybe to the patch antenna pattern which has a higher gain at the front than side, as compared to the dipole antenna which have equal gains horizontally. Because of this, the dipole antenna receives scattered waves with equal gain producing more fluctuations.

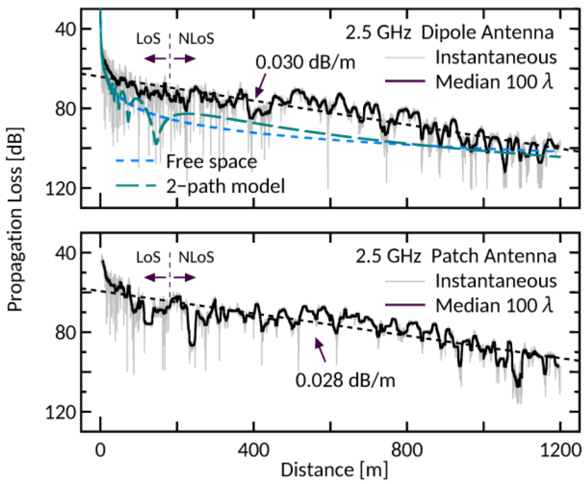

Fig. 3. Measurement Results for 2.5 GHz.

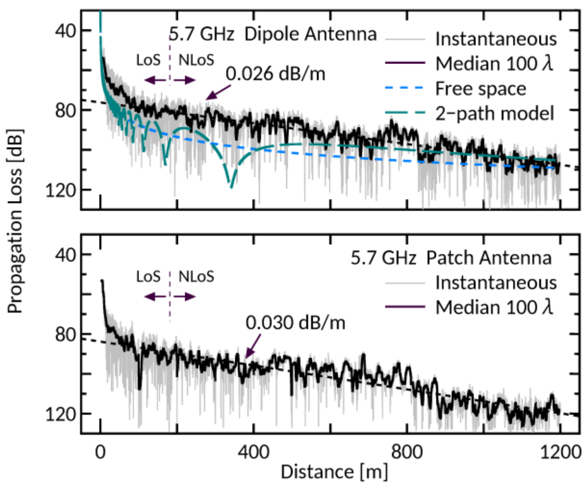

Fig. 4. Measurement Results for 5.7 GHz.

3. Attenuation Constant of Propagation Loss

Based on the literature, there is no empirical equation to solve for the attenuation constant of propagation loss for tunnels with curves and slopes. For comparison, (1) is used to calculate the attenuation constant d_v in dB/m based on [3] which is for a straight tunnel with LoS scenario. $K_v = 4.58$ is a coefficient depending on the shape of the tunnel cross section, λ is the wavelength in m, a and b are the tunnel cross section's width and height respectively in m, and $\varepsilon_r = 6.2$ is the relative permittivity. The resulting values are 0.0016 dB/m for 2.5 GHz and 0.0003 dB/m for 5.7 GHz.

On the other hand, based on the NLoS portion of the measurement data, the attenuation constant is about 0.03 dB/m. The difference is due to the NLoS environment. A line with decreasing slope corresponding to the attenuation constant is included in Figs. 3 and 4. These results are tabulated in Table I and also includes values for free space and 2-path model for comparison.

$$d_v = K_v \lambda^2 \left(\frac{1}{a^3 \sqrt{\varepsilon_r - 1}} + \frac{\varepsilon_r}{b^3 \sqrt{\varepsilon_r - 1}} \right) \qquad (1)$$

TABLE I
Attenuation Constant of Propagation Loss [dB/m]

Frequency [GHz]	Measurements		Calculation		
	Dipole	Patch	Free space	2-path model	Eq. (1)
2.5	0.030	0.028	0.014	0.023	0.0016
5.7	0.026	0.030	0.014	0.0078	0.00030

4. Conclusion

It is important to know the propagation loss to decide the communication area and frequency reuse for CBTC systems. The attenuation constant of the propagation loss is therefore an important value. Existing empirical equations to solve for the propagation loss are for straight tunnels with LoS scenario and therefore gives a small attenuation constant value. Based on our measurements, the attenuation constant in the NLoS region inside a tunnel for 2.5 GHz and 5.7 GHz ranges from 0.026 to 0.03 dB/m.

The present measurement campaign used a single-track tunnel. In the future, branching tunnels with double tracks and station facilities will be considered.

Acknowledgment

The authors would like to thank Harbin Metro Group Co., Ltd. and Nanjing Research Institute of Electronics Technology for their assistance during the on-site measurements, and Mr. Okada, Mr. Katori and Mr. Sato of Tektronix Inc. for their support in the data processing.

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