Measurements of the Propagation of UHF Radio Waves on an Underground Railway Train

Y. P. Zhang, Z. R. Jiang, T. S. Ng, *Senior Member, IEEE*, and J. H. Sheng

***Abstract*—Measurements of the natural propagation of UHF radio waves on an underground train are reported. Of prime interest are the natural propagation attenuation and the median signal level behavior. The propagation attenuation rates or the median signal level behaviors are found to correlate with the train carriages and frequency. On the front carriage, the propagation attenuation rate is 54 dB/100 m at 465 MHz and reduced to 21 dB/100 m at 820 MHz. However, on the rear carriage, it becomes 14.8 dB/100 m at 465 MHz and 7.8 dB/100 m at 820 MHz. It is shown that higher frequency is beneficial to the natural propagation and the train body greatly affects the natural propagation. Furthermore, the values of the path loss exponent are also given.**

***Index Terms*—Mobile radio propagation, underground railways.**

I. Introduction

MOBILE communications for underground railway trains are currently realized by the guided propagation of radio waves using the approach of leaky feeder [1]. They are also likely to be implemented by the natural propagation of radio waves utilizing the method of antenna [2]. Of the two, it is the latter that has recently drawn attention. Measurements of the natural propagation of radio waves at 2.5 GHz in an empty underground railway tunnel have been reported [3]. It is shown that the propagation attenuation is quite small in the platform and the straight section of the tunnel. However, the natural propagation undergoes great attenuation in the curved section of the tunnel and a sharp drop in the signal level occurs when the line-of-sight propagation path is obstructed due to the tunnel curvature. Such measurements actually provide very limited information on radio propagation characteristics in underground railway tunnels because the effects of the train on the natural propagation have not been considered. A train is a major scatter in an underground railway tunnel. It will severely block the natural propagation. On the other hand, a theoretical model based on ray-optical approach has been proposed to determine the time-variant radio links in high-speed train tunnels [4]. However, no experimental validation of the model has been made. In this paper, we contribute to the measurements of the natural propagation losses of UHF radio waves on an underground moving train. Specifically, it presents results of measurements taken at 465 and 820 MHz. We first describe the experimental conditions and the measurement system. Secondly, we analyze and discuss the experimental results, and finally, we make conclusion.

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II. Measurements

The measurements were made on a train moving between Stations Xizhimen and Chegongzhuang of Beijing Underground Railway. The train has six carriages. The length of each carriage is 19 m. The internal and external dimensions of the carriage are 2.65 m and 2.95 m wide, and 2.1 m and 3.6 m high, respectively. There are eight glass windows on each side of the carriage. A window has the length of 1.17 m and the width of 0.94 m. The ratio of the window area to the whole side area is 0.22 to 1. The quasi-straight arched tunnel between the two stations has the floor width of 5.8 m, the maximum height of 4 m, and the length of 980 m. It takes about 1 min for the train to travel.

The measurement system consists of a transmitting unit, a receiving unit, and a data acquisition unit. The transmitter output was 8 W at 465 MHz and 34 W at 820 MHz. The sensitivity of the R/S ESV receiver was -117 dBm. The gain of the transmitting antenna was 5 dBi at 465 MHz and 9 dBi at 820 MHz, while the gain of the receiving antenna was 3.5 dBi at 465 MHz and 5 dBi at 820 MHz. The data acquisition unit was set to log received signal level to a floppy disk every 7×10^{-6} s. When the measurements were being made, the transmitting unit was on the edge of the platform of Station Xizhimen, the receiving and the data acquisition units housed on a trolley was on the train. The radio channel was first excited by the vertically polarized transmitting antenna at the height of 1 m above the platform floor, and then was sounded by the vertically polarized receiving antenna at the height of 1 m above the train floor. Fig. 1 shows the measurement setup with respect to the train movement.

III. Analysis and Results

The median signal level over a distance of 40λ was computed at 40λ intervals for each measurement run. The propagation attenuation rates were calculated with the median signal levels between the maximum and a threshold. Since the receiver passed by the transmitter as the train moved, the maximum would occur at the shortest distance between the transmitter and the receiver. The threshold was determined after careful observation of the propagation attenuation of the measured results. For most of

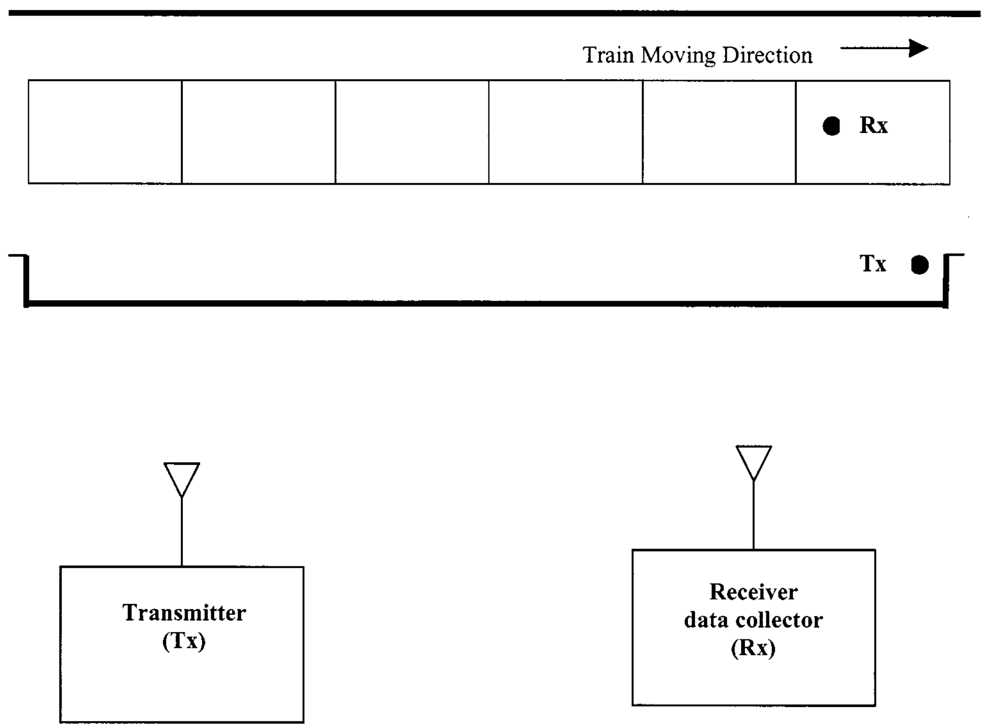

Fig. 1. Measurement setup with respect to the train movement.

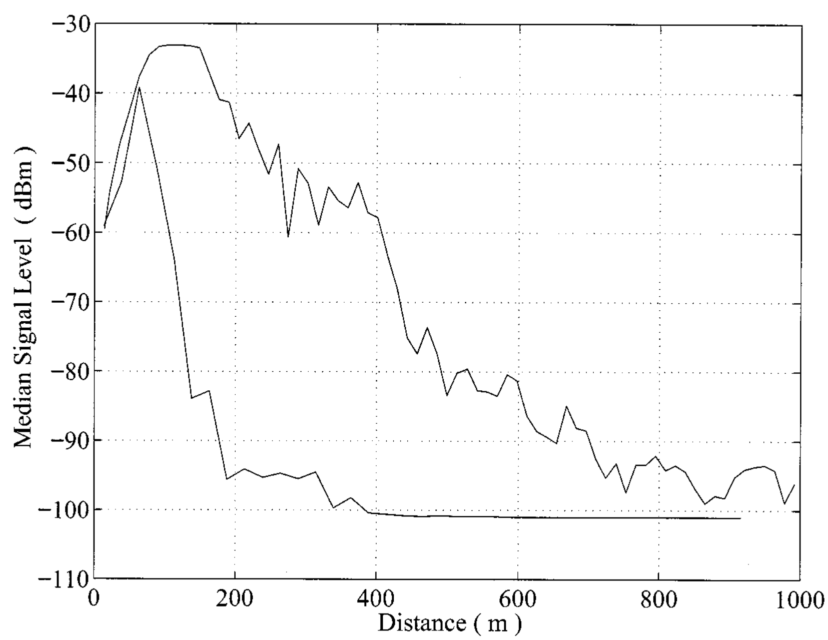

Fig. 2. Median signal levels on the front and rear carriages at 820 MHz against the distance that the train travels.

them, the threshold was at −100 dBm, that is, the median signal levels smaller than −100 dBm were excluded.

Fig. 2 shows the median signal levels at 820 MHz on the front and rear carriages against the distance that the train travels. It is evident that the median signal on the front carriage is much weaker and more attenuated as compared with that on the rear carriage. For instance, at the separation distance of 200 m between the transmitter and the receiver, the median signal level is −47.0 dBm on the rear carriage and −94.0 dBm on the front carriage. The weaker median signal level on the front carriage is due to more severe shadowing effect. The propagation attenuation rate is 21 dB/100 m with the standard deviation of 9.84 dB for the receiver on the front carriage and reduced to 7.8 dB/100 m with the standard deviation of 6.55 dB for the receiver on the rear carriage. Curves in Fig. 2 are two extreme examples. They set the

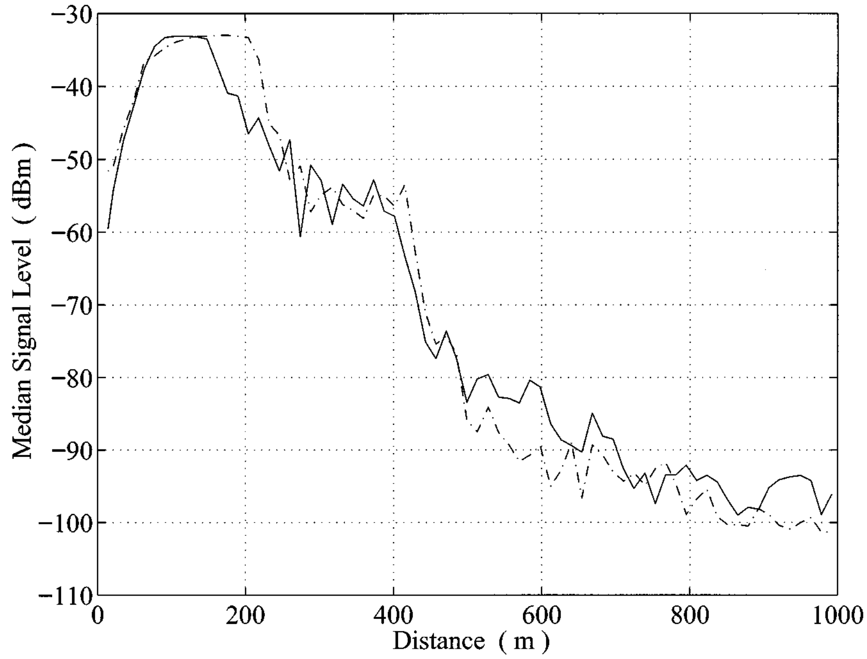

Fig. 3. Median signal levels on the rear carriage at 820 MHz against the distance that the train travels.

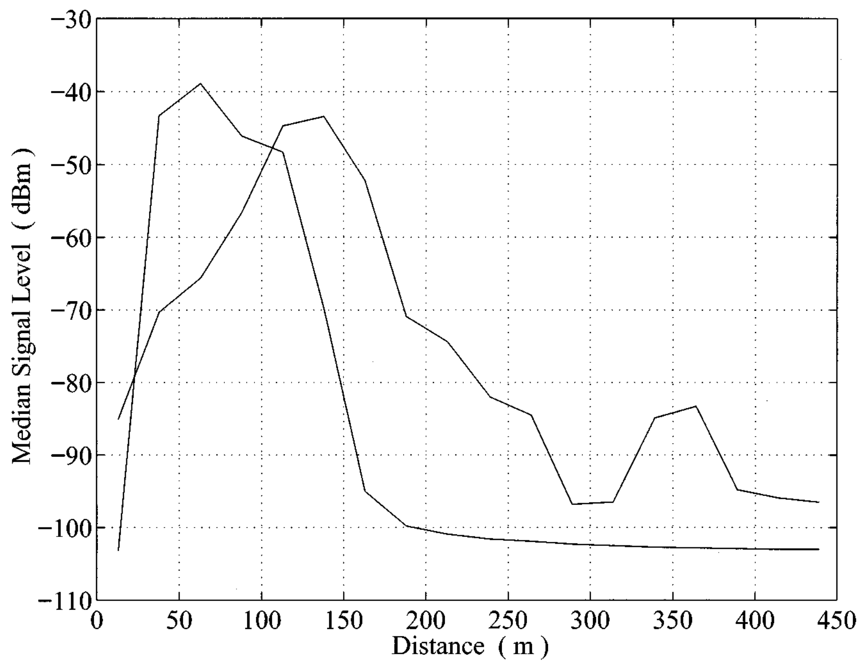

Fig. 4. Median signal levels on the front and rear carriages at 465 MHz against the distance that the train travels.

lower and upper bounds for the median level behavior and the natural propagation attenuation of 820 MHz radio waves on the moving underground train. They also indicate that the natural propagation is correlated with the train carriages. The more carriages are between the transmitter and the receiver, the higher propagation losses are. Here it is worthwhile mentioning that the natural propagation loss at 820 MHz due to this tunnel itself is 3.24 dB/100 m. Obviously, the existence of the train greatly increases the natural propagation loss.

Fig. 3 illustrates the median signal levels at 820 MHz on the rear carriage against the distance that the train travels. Continuous and discontinuous curves represent the median signal levels for the cases of the receiver being relatively stationary and in motion to the train, respectively. They simulate the two states of passengers using cellular phones on underground railway trains. It can be seen that there are no much differences in the median signal level behavior and the natural propagation attenuation for both cases. This is expected since the speed of the

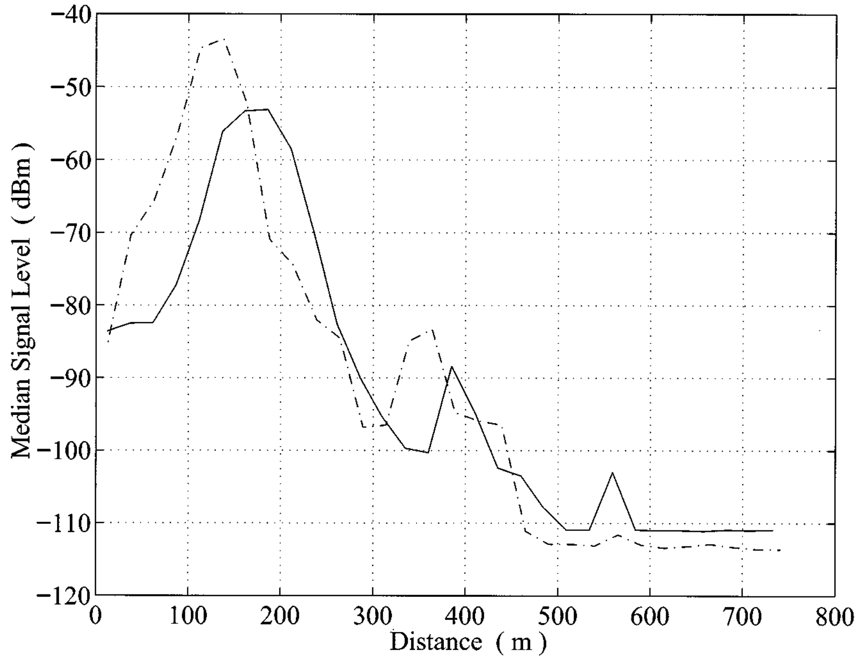

Fig. 5. Median signal levels on the rear carriage along the distance at 465 MHz against the distance that the train travels.

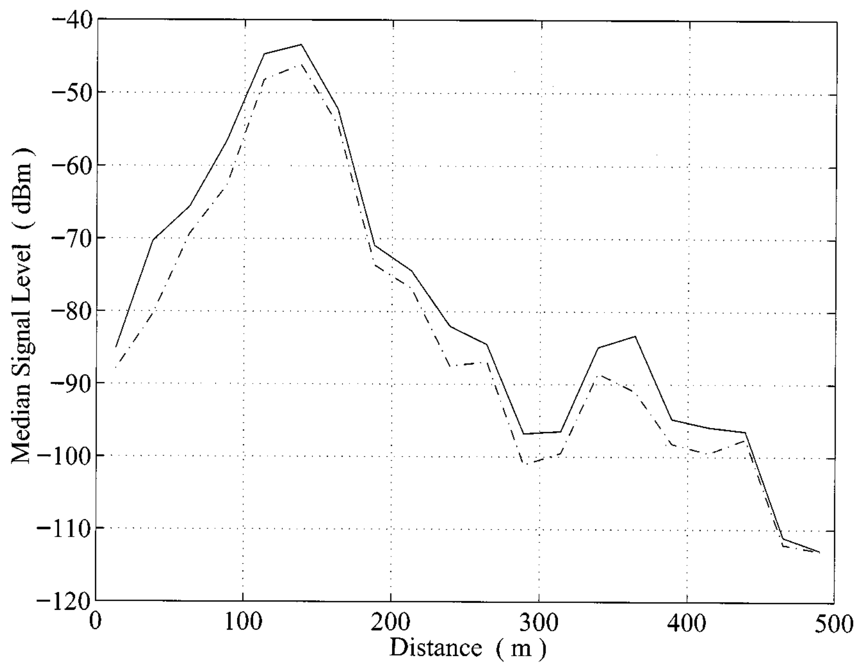

Fig. 6. The 50 and 90 percentile signal levels on the rear carriages at 465 MHz against the distance that the train travels

receiver to the train is much slower than that of the train to the transmitter.

Figs. 4 and 5 display the corresponding measured results at 465 MHz. It is interesting to note that the natural propagation suffers high propagation loss. The natural propagation loss due to this tunnel itself at 465 MHz is 10.1 dB/100 m. The propagation attenuation rates increase to 54 dB/100 m with the standard deviation 7.1 dB for the receiver on the front carriage and to 14.8 dB/100 m with the standard deviation of 8.9 dB for the receiver on the rear carriages, respectively. The comparison of the results at 465 MHz with those at 820 MHz shows the higher frequency yields more fluctuations in the median signal levels and lower losses to the natural propagation.

Figs. 6 and 7 show another examples of the measurements at 465 MHz and 820 MHz, respectively. They were measured on the rear carriage. Continuous and discontinuous curves represent the 50 and 90 percentile signal levels, respectively. The percentiles are a reflection of the distribution of the signal levels

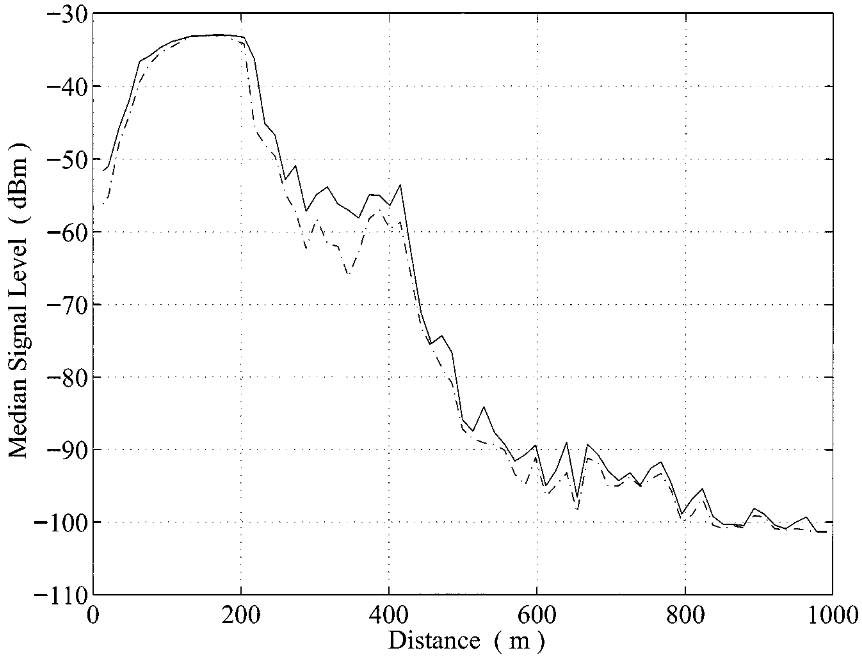

Fig. 7. The 50 and 90 percentile signal levels on the rear carriages at 820 MHz against the distance that the train travels.

TABLE I
PATH LOSS EXPONENT AND STANDARD DEVIATION

Frequency (MHz)	Exponent (n)	Standard deviation (dB)	Carriage
465	12.45	9.46	front
	9.72	7.15	rear
820	8.58	6.40	front
	8.17	4.58	rear

and give some indication of the spread of the signal levels. This is useful to estimate the coverage and co-channel interference.

Furthermore, we also developed a path loss exponent model from the data. The values of the loss exponent are found from the linear regression analysis. They are given in Table I together with the standard deviation.

IV. CONCLUSION

The measurements of the natural propagation of radio waves at 465 and 820 MHz on an underground train have been presented. The path loss exponent model has been developed. The propagation attenuation rates at both frequencies on the train front and rear carriages have been obtained. They are 54 dB/100 m and 14.8 dB/100 m at 465 MHz and reduced to 21 dB/100 m and 7.8 dB/100 m at 820 MHz. The propagation attenuation rates are correlated with the train carriages and frequency. The train body greatly affects the natural propagation of UHF radio waves. Higher frequency is beneficial to the natural propagation.

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Z. R. Jiang photograph and biography not available at the time of publication.

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