C–3–5 EXPERIMENTAL TEST RESULTS OF 800 MHz BAND MOBILE RADIO PROPAGATION IN HIGH-WAY TUNNELS

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I INTRODUCTION

Radio wave propagation in the road-way tunnels have been being currently researched for the system design of such land mobile radio communication as emergency, disaster, public telephone and so on [1] , [2] , [3] . There are many factors affecting the mobile radio propagation in tunnels, or, carrier frequency, polarization, tunnel sectional figure, tunnel bending degree of propagation direction, motor-car traffic in tunnel and so on.

This report presents a few experimental test results of 800 MHz band mobile radio propagation in high-way tunnels.

Experimental tests were carried out on vertical and horizontal polarization characteristics and influence of motor-car traffic on mobile radio propagation.

II EXPERIMENTAL ARRANGEMENTS

Tunnels

The tunnels under test were cable tunnel (underground passage in Yokosuka Electrical Communication Laboratory), Sasago Tunnel (Chūō High-Way) and Chiyoda Tunnel (Metropolitan High-Way).

Table 1 Tunnel Configuration

Tunnel	Cable	Sasago	Chiyoda
Cross Section	2m; 3m	4.7m; 9.6m	4.5m; 8.6m
Plan	400m	4000m; 400m	600m; 300m
Motor-car traffic density N	0 cars/100m	0 cars/100m closed	1-9 cars/100m

Table 1 shows these tunnel configurations. On each tunnel, material of side walls, floor and roof is ferro-concrete. In cable tunnel, the floor is covered with iron plate of 2 m in width.

In Sasago Tunnel, the side walls and roof are covered with PC-board (ingredient : asbests and cement) on ferro-concrete surface.

Measurement

a) Polarization Characteristics

Measurements were carried out on 800 MHz band in cable and Sasago Tunnel.

In cable tunnel, radiating and receiving antennas were $\lambda/2$ dipoles. Radiating antenna was located almost center of tunnel cross section and almost 50 m from tunnel mouth. Receiving antenna was moved to propagation direction keeping to almost center position of tunnel cross section. Measurements were carried out for vertical polarization (V) and horizontal polarization (H).

In Sasago Tunnel, radiating antennas were a $\lambda/2$ dipole (V) and a $\lambda/2$ cross dipole (VH). Those were located almost center of tunnel cross section and about 500 m from tunnel mouth. Receiving antennas were a $\lambda/4$ whip (V) and a $\lambda/2$ cross dipole (VH) installed on the roof of mobile station vehicle (antenna height : 1.5 m above the road surface).

b) Influence of Motor-car Traffic

Measurements were carried out on 800 MHz band for vertical polarization in Chiyoda Tunnel. Radiating antenna was a Yagi antenna with a gain of about 10 dB compared to a $\lambda/2$ dipole. Radiating antenna was located about 0.5 m above the side wall and about 1.0 m below the roof of the tunnel. All results, however, have been referenced to a $\lambda/2$ dipole radiating antenna. Receiving antenna was a $\lambda/4$ whip installed on the mobile station vehicle.

Data Processing

The measured data were segmented every 10 m running distance. The median of 10 m running distance was called "10 m small-section median". This was a basic factor of data processing.

III MEASUREMENT RESULTS AND CONSIDERATION

a) Polarization Characteristics

Fig. 1 shows an example of received field strength for radiating antenna-receiving antenna vertical polarization (V-V) and horizontal polarization (H-H), in cable tunnel. As shown in Fig. 1, the field strength behavior is divided into large fluctuation region and small fluctuation region.

i) Large fluctuation region : Received field strength includes deep fading and decreases with distance. This region was observed within near distance from the radiating antenna.

ii) Small fluctuation region : Received field strength includes shallow fading and is inversely proportional to distance between antennas. This region was observed farther distance.

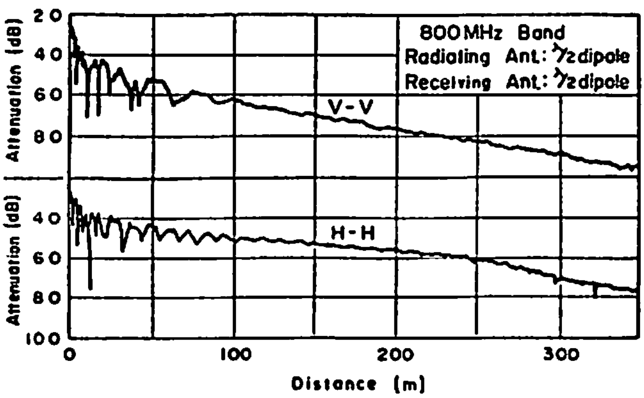

Fig.1 Example of received field strength

Fig. 2 shows the average attenuation between antennas in cable tunnel. Each measured value in Fig. 2 is an average value of "10 m small-section median". In Fig. 2, the attenuation gradient for V-V is larger than that for H-H.

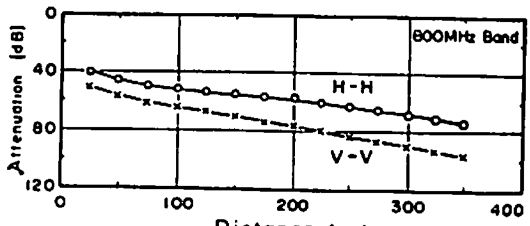

Fig.2 Polarization Characteristics (Cable Tunnel)

Propagation in a tunnel have been dealt with much the same as propagation in a wave guide with lossy modes (wave guide theory) or a result of the reflection waves from the side walls, floor and roof (ray method). By wave guide theory [2] , within small fluctuation region, the average basic attenuation is given by the following equation for a rectangular cross section of tunnel.

For vertical polarization

$$L_v = \frac{4.343\ \lambda^2 z}{d_1^3 \sqrt{k-1}} (1 + k x^3)\ [\mathrm{dB}] \text{ ---- } (1)$$

For horizontal polarization

$$L_h = \frac{4.343\ \lambda^2 z}{d_1^3 \sqrt{k-1}} (k + x^3)\ [\mathrm{dB}] \text{ ---- } (2)$$

Where, λ : wave length [m], z : distance [m] , d_1 and d_2 : tunnel cross section width and height [m] , k : dielectric constant of the side walls, floor and roof in tunnel ($k>1$), x : d_1/d_2.

The attenuation difference for polarization depends on values in parenthesis of Eq. (1) and (2). Therefore, L_V and V_h are due to x as in the following

i) $x=1$ ($d_1=d_2$) -- $L_V=L_h$

ii) $x>1$ ($d_1>d_2$) -- $L_V>L_h$

iii) $x<1$ ($d_1<d_2$) -- $L_V<L_h$

These result agrees with the experimental results in cable tunnel (Fig. 2).

Namely, the attenuation for V-V is larger than that for H-H, because $x>1$.

Table 2 shows measurement values and calculated values by Eq. (1) and (2) ($k = 5$). Values are the attenuation per 100 m distance within small fluctuation region. These values agree fairly well.

As above described, attenuation seems to be small in exciting in the direction of the major axis in rectangular cross section tunnel.

On actual high-way tunnel, measurements were carried out.

Fig. 3 shows an example of received field strength in Sasago Tunnel. Polarization V-V was measured by a $\lambda/2$ dipole radiating antenna and a $\lambda/4$ whip receiving antenna. VH-V was measured by a $\lambda/2$ cross dipole radiating antenna and a $\lambda/4$ whip receiving antenna. VH-VH was measured by $\lambda/2$ cross dipole radiating and receiving antennas. As shown in Fig. 3, V-V and VH-VH also had large fluctuation and small fluctuation regions. VH-V, however, had a long periodic fluctuation beyond about 3000 m, as the line of sight path was interrupted by a curvature in the road surface plane.

Table 2 Measurement and Calculated Value

Polarization	Cable Tunnel		Sasago Tunnel	
	V-V	H-H	V-V	VH-VH
Measurement Value (dB/100 m)	13	9	2	0.8
Calculated Value (dB/100 m)	18	8	1.3	0.4

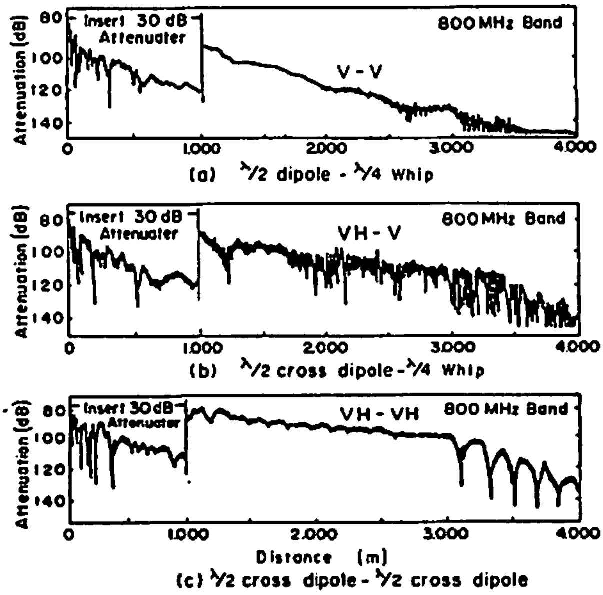

Fig. 3 Example of received field strength

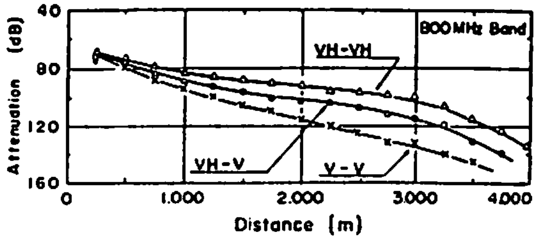

Fig. 4 Polarization Characteristics (Sasago Tunnel)

Fig. 4 shows the average attenuation between antennas in Sasago Tunnel. In Fig. 4, the attenuation gradients are large beyond about 3000 m. It seems to be cause an out of sight radiating antenna as a curvature in the road surface plane.

Table 2 also shows measurement values and calculated values. The calculated value for VH-VH was calculated by Eq. (2). That is reason why V and H radiating powers, at the same time, decrease according to Eq. (1) and (2), respectively.

Consequently, beyond a certain distance, the power of H seems to become a dominant in the tunnel. The received field strength seems to depend on it strongly.

For VH-V in Fig. 4, the following holds. A $\lambda/4$ whip vertical receiving antenna seems to receive not so much the power of V as the power of H beyond a certain distance. The phenomenon appears in Fig. 3 (b). Namely, the receiving field strength includes a deep fading beyond about 1500 m due to polarization mismatch.

b) Influence of Motor-Car Traffic

Fig. 5 shows the influence of motor-car traffic on 800 MHz band for V-V, in Chiyoda Tunnel. N, shown in Fig. 5, is motor-car traffic density (number of passing motor-cars per 100 m tunnel length).

As shown in Fig. 5, attenuation becomes larger as motor-car traffic density increase. Motor-car traffic density influences the attenuation gradient. Of course, the attenuation gradient is larger than calculated value by Eq. (1), in order to include the loss by motor-car traffic.

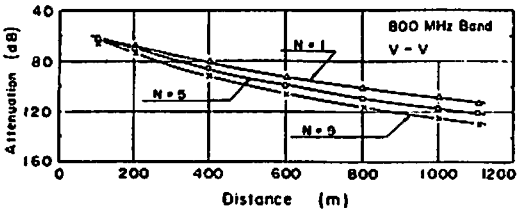

Fig.5 Influence of motor-car traffic (Chiyoda Tunnel)

IV CONCLUSION

Propagation tests were carried out on 800 MHz band in several tunnels.

Results show that

a) attenuation is small in exciting in the direction of major axis in rectangular cross section tunnel,

b) motor-car traffic density has an influence on attenuation gradient .

Further examination will be required on frequency dependence, tunnel sectional figure, tunnel bending degree of propagation direction.

Acknowledgment

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Reference

[1] D.O.Reudink, "Mobile Radio Propagation in Tunnels", IEEE Veh. Tech. Croup Conf. December 2-4, 1968, San Francisco, Calif.

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