# Base Station Vertical Space Diversity for Land Mobile Radios

Yoshio EBINE , Tatsumi TAKAHASHI and Yoshihide YAMADA
NTT Radio Communication Systems Laboratories
Yokosuka, Kanagawa, Japan

## 1. INTRODUCTION

Diversity reception is one of the most effective techniques available to overcome the deep fading in mobile radios. The most common diversity scheme at the base station is space diversity(1). In this scheme, two antennas are arranged in the horizontal plane. Vertical space diversity has advantages over horizontal space diversity from the viewpoint of area required on the antenna tower platform. Past studies on vertical space diversity were limited to examinations of high antennas(2),(3). No study has been reported on low antennas.

This paper theoretically and experimentally investigates vertical space diversity for both high and low land mobile base station antennas. The optimum antenna spacing to yield the maximum diversity gain is also given.

## 2. CORRELATION CALCULATION MODEL

In a base station employing vertical space diversity, two antennas are utilized with a spacing H as shown in Fig. 1. The #2 antenna (lower antenna) height is $H_{bt}$. The correlation coefficient $\rho_e$ of the received signal envelopes can be expressed by(4)

$$\rho_e = \frac{\left| \int_{-\pi/2}^{\pi/2} G_1^*(\theta)\cdot G_2(\theta)\cdot P(\theta)\cdot exp\{j\beta H cos(\theta)\}\cdot d\theta \right|^2}{\int_{-\pi/2}^{\pi/2} G_1^*(\theta)\cdot G_1(\theta)\cdot P(\theta)\cdot d\theta \times \int_{-\pi/2}^{\pi/2} G_2^*(\theta)\cdot G_2(\theta)\cdot P(\theta)\cdot d\theta}, \qquad (1)$$

where $G_1(\theta)$ and $G_2(\theta)$ are radiation patterns of the two antennas, $\beta$ is the wave number, $*$ is the complex conjugate, and $P(\theta)$ is the distribution of incoming waves. The source extent of incident fields due to a single mobile unit is thought to be limited to a small area whose radius is R and separated by a distance L from the base station. For $P(\theta)$, the following Gaussian distribution is often employed(2).

$$P(\theta) = exp\{-(\theta-\theta_i)/2S^2\}/\sqrt{(2\pi S^2)}, \qquad (2)$$

where $\theta_i$ is the direction of the principal incoming waves. The standard deviation S indicates the spread width of incoming waves, and this is nearly the same as $\tan^{-1}(2R/L)$.

## 3. DIVERSITY EFFECT

*Correlation coefficient and antenna spacing*: Calculated correlation coefficients for various antenna spacing and standard deviations of incoming waves are shown in Fig. 2. Measured data are also plotted in the same figure, as indicated by black ( $H_{bt}$ = 45m ) and white ( $H_{bt}$ = 15m ) circles. The field experiments were carried out at 1.5GHz in a Tokyo business district where the average building height is approximately 15m. Each antenna was composed of 4 dipole elements and the beam width of the vertical and horizontal plane were 10° and 180°, respectively. Prior results for $H_{bt} = 35$m at 900MHz[2] are also given in Fig. 2. The measured results are on average of the correlation coefficients over the range $1\text{km} < L < 6\text{km}$. Experimental results for $H_{bt} = 45$m at 1.5GHz and for $H_{bt} = 35$m at 900MHz agree well with the theoretical results at a standard deviation of $S = 0.4°$, and show the independence of the frequencies. For a $H_{bt} = 15$m, on the other hand, the measured correlation coefficients are about one third those for $H_{bt} = 45$m. The effective S for $H_{bt} = 15$m is considerably larger than that for $H_{bt} = 45$m. At a small $\rho_e$, $\rho_e \approx 0.2$ is considered the distinguishable lower limit, to maintain the accuracy of measured correlation coefficients. Judging from $\rho_e > 0.2$ values, standard deviations of $0.9° < S < 1.2°$ can explain the measured data. The spread angle of incoming waves for low antennas is three times that for higher antennas.

*Correlation coefficient dependence on distance from the base station*: Variations in the correlation coefficients of distance L between the base and mobile stations are measured for $H_{bt} = 45$m and 15m, and for antenna spacing $H = 20$ and 12 wavelengths, as shown in Fig. 3. For $H_{bt} = 45$m, the correlation coefficients increase with distance L. This is because the distribution angles of incoming waves ($\approx S$) are considered to become smaller as L increases.

For $H_{bt} = 15$m, the correlation coefficients becomes very small and show no dependence on distance L. If scatterers are located near the base station, correlation coefficients will be reduced.

*Effective antenna gain dependence on antenna height*: To measure effective antenna gain, the reference antenna was placed at a constant height of 45m. The measured antennas were lowered from $H_{bt}$ between diversity branches as shown in Fig. 1. The measured effective antenna gain is depicted in Fig. 4 for $H_{bt} = 45$m and 15m. The gain difference between $H_{bt} = 45$m and 15m is 6dB when $H = 0$. This is considered to be reasonable, judging from the extrapolation of the Okumura curve[5] to $H_{bt} = 15$m. The effective antenna gain at $H_{bt} = 45$m deviates within ± 1dB with the variation of H. On the other hand, for $H_{bt} = 15$m, the effective antenna gain decreases with increasing H. The rate of decrease is approximately expressed as $-0.25\text{dB}/(H/\lambda)$.

The received signal level difference of 3dB, resulting in a diversity gain reduction of about 2dB[6], is considered acceptable. In Fig. 4, reduction of 3dB in the effective antenna gain corresponds to an antenna spacing of within 10 wavelengths, for $H_{bt} = 15$m.

## 4. CONCLUSION

A field experiment on vertical space diversity of a base station was carried out at 1.5 GHz in a Tokyo business district. For relatively a high antenna (45m), the measured data agree well with prior results measured at 900MHz, and with the calculations.

Measurements for a low antenna, nearly as high as the surrounding buildings, were made for the first time in this study. The correlation coefficients are considerably smaller than those for the 45m-high base station antenna. Moreover, the received signal levels for the lower antenna decreased about 6dB compared with those for the 45m-high antenna. Consequently, it was clarified that antenna spacing of less than 10 wavelengths is needed in order to achieve sufficient diversity effects.

## 5. REFERENCES

(1) W.C.Y.Lee: "Mobile Communications Engineering", McGraw-Hill, p273, 1982

(2) F.Adachi ,et al.,: "Crosscorrelation Between the Envelopes of 900MHz Signals Received at a Mobile Radio Base Station Site", IEE proc. Vol. 133, No. 6, 1986

(3) S.B.Rhee, G.I. Zysman: "Results of Suburban Base station Spatial Diversity Measurements in the UHF band", IEEE trans., Vol. COM-22, No. 10, p1630, 1974

(4) Y.Ebine , Y.Yamada: "Vehicular-Mounted Diversity Antennas for Land Mobile Radios", 38th IEEE Vehicular Technology Conference, p326, 1988

(5) Y.Okumura, et al., : "Field Strength and Its viability in *VHF* and *UHF* Land-Mobile Radio Service", Rev. Elec. Commun. Lab., Vol 16, No.9-10, 1968

(6) S.Suwa, T.Hattori: "A Study on Selection Diversity With Unequal Median Values and Correlated Envelope Signal", EICE'84(Jpn.) National Conference No.2428

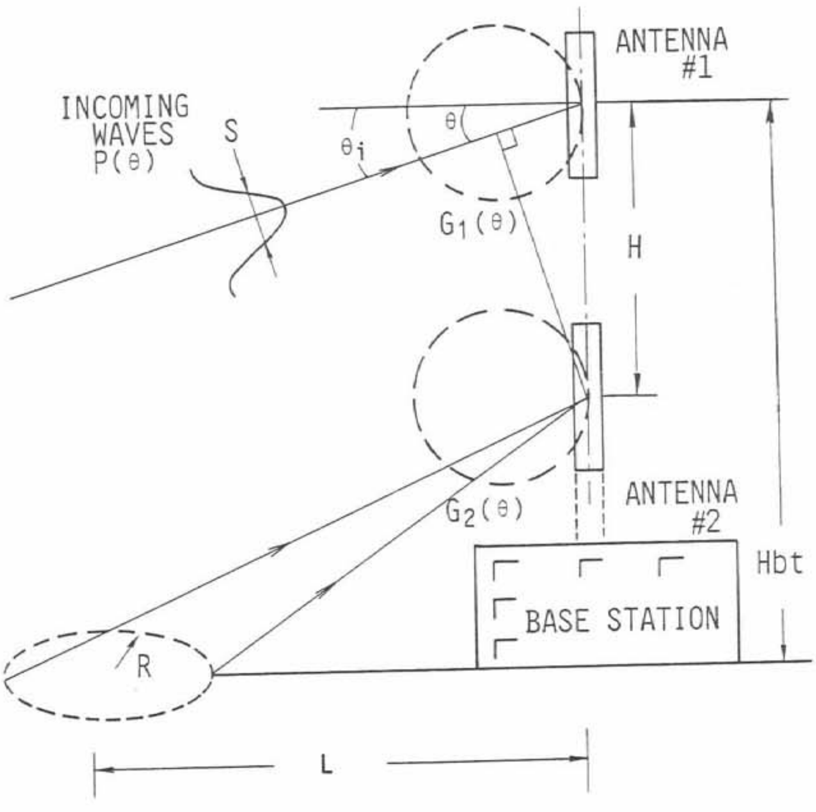

Fig. 1 CALCULATION MODEL.

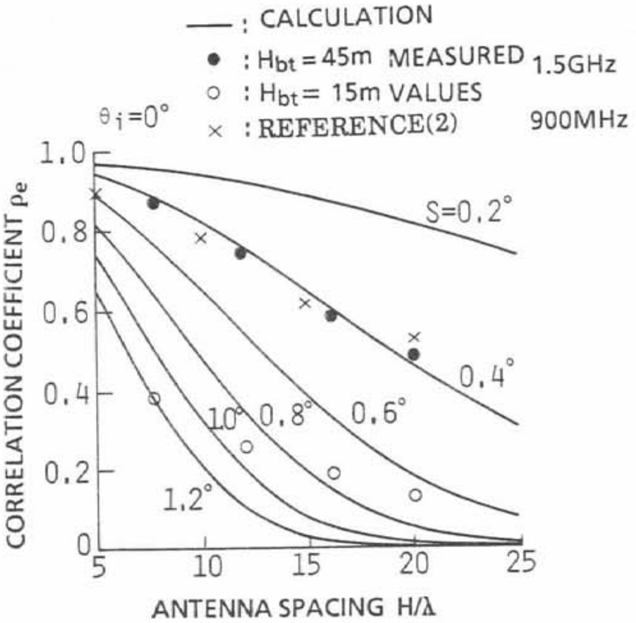

Fig. 2 ANTENNA SPACING VS. CORRELATION.

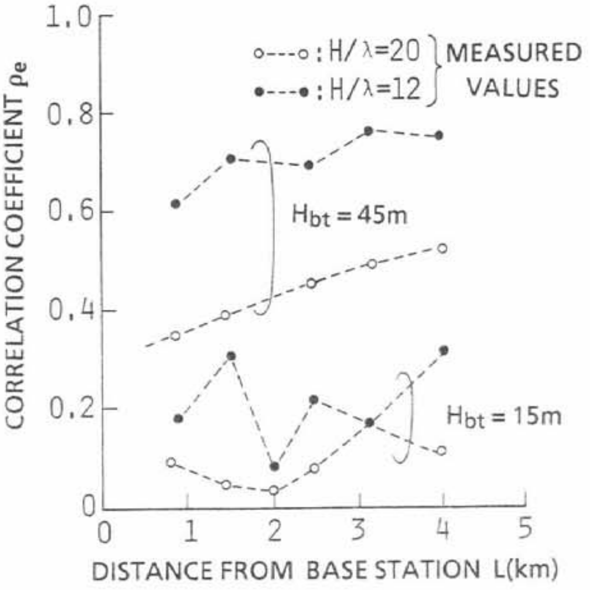

Fig. 3 BETWEEN BASE AND MOBILE STATIONS TO DISTANCE.

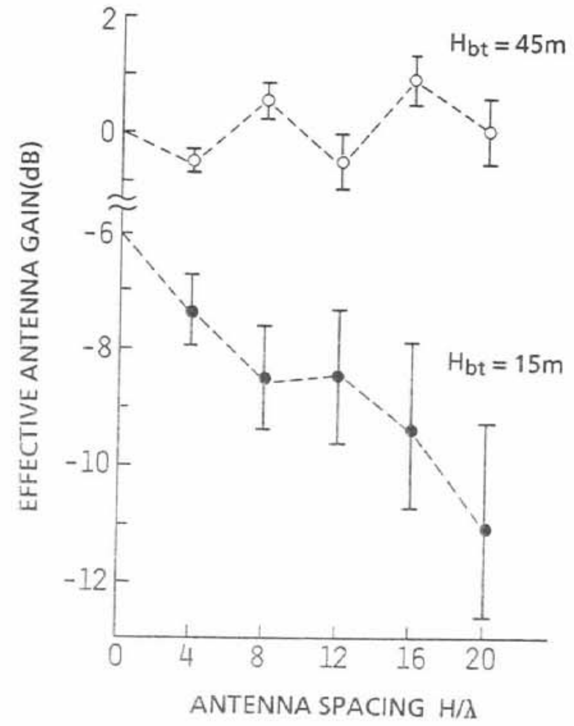

Fig. 4 EFFECTIVE ANTENNA GAIN DEPENDENCE ON ANTENNA HEIGHT.