# Performance Evaluation of Three-dimensional Spatial Channel Emulator for MIMO-OTA Testing

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## Abstract

This paper proposes the simple method to evaluate the spatial correlation characteristics in three-dimensional spatial channel emulator and clarify the adequate probe antenna configuration considering actual radio propagation characteristics in urban macrocell environment.

**Keywords :** Spatial channel emulator MIMO-OTA testing Mobile propagation

## 1. Introduction

Up to now, Spatial Channel Emulator (or SCE) to evaluate MIMO performance of mobile terminals has been investigated under two-dimensional way, which means probe antennas in radiation part being circularly arrayed in horizontal plane as shown in the figure 1 [1, 2]. Hereafter, this configuration is called probe-ring. When assuming SCM (Spatial channel model) or SCME (SCM Extended) as a MIMO channel model, Angle-of-arrival (or AOA) distribution of radio waves is defined in only horizontal plane [3, 4]. The AOA is however distributed three-dimensionally in actual mobile communication environment, even though elevation angle spread is narrower than azimuth angle spread. So, three-dimensional AOA distribution should be considered to evaluate the MIMO performance of mobile terminal more strictly.

In order to implement three-dimensional AOA distribution in SCE, probe antennas have to be spherically arranged around mobile terminal. This causes cost increase of the SCE. Note that we know that it is possible to reduce the required number of probe antennas when focusing to the relationship between AOA distribution and MIMO antenna configuration of mobile terminal with respect to the spatial correlation [2]. In [2], we have clarified the adequate probe antenna configuration in two-dimensional SCE (or 2D-SCE). In this paper, we propose the simple method to evaluate the spatial correlation characteristics as performance in three-dimensional SCE (or 3D-SCE) and clarify the adequate probe antenna configuration.

## 2. Evaluation Method

### 2.1 Evaluation Model

Figure 2 shows the model to evaluate the spatial correlation characteristics in 3D-SCE. The number of reception points is two. The reception points #1 and #2 are located at the origin and at the point of ($r_0$, $\alpha_0$, $\beta_0$), respectively. Here, it is assumed that a radius of the sphere on which the probe antennas are set is great longer than the separation distance between reception points #1 and #2, $r_0$.

In order to simplify the evaluation, we define the three-dimensional probe antenna configuration is modelled by vertical array of the probe-rings as shown in Fig. 2, where the number of probes is same in all probe-rings and the radius of each probe-ring is defined so that all probe antennas are on the spherical surface. The installation range of probe-rings is $2\Theta_\beta$ with center of $\beta_a$ (or ($\beta_a$-$\Theta_\beta$, $\beta_a$+$\Theta_\beta$)) and installation interval is $\Delta\beta$. Note that the upper bound of "$\beta_a$+$\Theta_\beta$" is π/2 and the lower bound of "$\beta_a$-$\Theta_\beta$" is -π/2. So, maximum of $2\Theta_\beta$ is π.

### 2.2 Evaluation Indicator

In general, when the radio waves three-dimensionally arrive at reception points, spatial correlation between reception point #1 and #2 shown in Fig. 2 are expressed by

$$\rho(r_0,\alpha_0,\beta_0)=\frac{\int_{-\pi/2}^{\pi/2}\int_{-\pi}^{\pi}P(\alpha,\beta)\cdot e^{jk_0r_0\cos(\xi)}\cos(\beta)d\alpha d\beta}{\int_{-\pi/2}^{\pi/2}\int_{-\pi}^{\pi}P(\alpha,\beta)\cdot\cos(\beta)d\alpha d\beta} \tag{1}$$

where $k_0$ is wave number, $P(\alpha, \beta)$ is three-dimensional power angular spectrum and

$$\cos(\xi)=\sin(\beta_0)\sin(\beta)+\cos(\beta_0)\cos(\beta)\cos(\alpha-\alpha_0). \tag{2}$$

Now we assume that $P(\alpha, \beta)$ equals $P(\alpha)P(\beta)$, where $P(\alpha)$ and $P(\beta)$ are azimuth and elevation power angular spectrums, respectively. When $\beta_0$ equals $\pi/2$, the equation (1) becomes

$$\begin{aligned}\rho(r_0,\alpha_0,\pi/2)&=\int_{-\pi/2}^{\pi/2}P(\beta)\cdot e^{jk_0r_0\sin(\beta)}\cos(\beta)d\beta\Big/\int_{-\pi/2}^{\pi/2}P(\beta)\cos(\beta)d\beta\\&=\sum_{m=-\infty}^{\infty}J_m(k_0r_0)\frac{B(m+1)+B(m-1)}{2}\ \left(\equiv\rho_\beta(r_0)\right)\end{aligned} \tag{3}$$

where

$$B(l)=\int_{-\pi/2}^{\pi/2}P(\beta)\cdot e^{jl\beta}d\beta\Big/\int_{-\pi/2}^{\pi/2}P(\beta)\cos(\beta)d\beta\cdot \tag{4}$$

From the equations (3), (4), we understand that the spatial correlation with $\beta_0$ of $\pi/2$ depends only on elevation power angular spectrum, $P(\beta)$. This means that the difference between the performance in 3D-SCE and that in 2D-SCE becomes a maximum when the reception points are vertically arrayed. In this paper, we evaluate the spatial correlation characteristics in 3D-SCE based on Eq. (3). Hereafter the spatial correlation based on (3), $\rho_\beta(.)$ is called vertical spatial correlation.

In 3D-SCE, the equation (4) expresses that the probe-rings exist in an infinity over ($-\pi/2$, $\pi/2$). On the other hand, when the number of probe-rings is limited as shown in Fig. 2, the equation (4) becomes

$$\tilde{B}(l;\Theta,\Delta\beta)=\sum_{k=-[\Theta/\Delta\beta]}^{[\Theta/\Delta\beta]}P(\beta_a+k\Delta\beta)\cdot e^{jl(\beta_a+k\Delta\beta)}\Big/\sum_{k=-[\Theta/\Delta\beta]}^{[\Theta/\Delta\beta]}P(\beta_a+k\Delta\beta)\cos(\beta_a+k\Delta\beta)\cdot \tag{5}$$

In Eq. (5), the function of $[x]$ is a Gauss symbol where the value is the maximum integer not exceeding $x$. Therefore, we can define the estimation error of vertical spatial correlation resulting from the limited number of probe-rings as

$$\Delta\rho(r_0)=\sum_{m=-\infty}^{\infty}J_m(k_0r_0)\frac{\Delta B(m+1)+\Delta B(m-1)}{2},\ \Delta B(l)=\tilde{B}(l)-B(l) \tag{6}$$

where $J_m(.)$ is the Bessel function of the first kind of the $m^{\text{th}}$ order. In this paper, the estimation error, $\Delta\rho$ is an indicator to evaluate the performance of 3D-SCE. Note that the function of $B(l)$ is approximated by $\tilde{B}(l;\Theta=\pi/2,\ \Delta\beta=\pi/360)$ in the next section.

## 3. Performance of 3D-SCE

We show the numerical results calculated by Eq. (6) assuming the elevation power angular spectrum, $P(\beta)$ of Laplace distribution as defined by

$$P(\beta)=\frac{1}{\sqrt{2}\sigma_\beta}\exp\left(\frac{-|\beta-m_\beta|}{\sigma_\beta/\sqrt{2}}\right)\cdot \tag{7}$$

In Eq. (7), $m_\beta$ and $\sigma_\beta$ are mean value (or mean AOA) and standard deviation (or angle spread) of the distribution, respectively. Here, we have already confirmed that average of elevation power angular spectrum can be approximated by Laplace distribution with ($m_\beta$, $\sigma_\beta$) of (10 deg., 20 deg.) in urban macrocell propagation environment [5]. By the way, we believe that the separation between antenna elements of MIMO mobile terminal is within 1.5 $\lambda$, where $\lambda$ is wave length and the value of 1.5 $\lambda$ with 2GHz is 22.5 cm. So, we evaluate the maximum value of absolute estimation error, i.e. max( $|\Delta\rho|$ ) when $r_0$ is within 1.5 $\lambda$. In addition, we define the ceter of installation range, $\beta_a$ equals $m_\beta$.

Figures 3(a), (b) show the relationship between the installation range of probe-rings, $2\Theta$ and the maximum estimation error with ($m_\beta$, $\sigma_\beta$) as parameters. Here, we set $\Delta\beta$ of 0.5 degree (or $\pi/360$) for assuming the number of probe-rings is not limited. These figures show that the estimation error becomes increase when the installation range is smaller mostly depending on the

value of the angle spread, $\sigma_\beta$. From these results, we understand that the required installation range, $2\Theta$ is equal to or larger than 68 degrees when allowable error is 0.1 in the case of ($m_\beta$, $\sigma_\beta$) = (10 deg., 20 deg.).

Figures 4(a), (b) show the relationship between the installation interval of probe-rings, $\Delta\beta$ and the maximum estimation error with ($m_\beta$, $\sigma_\beta$) as parameters. Here we set the installation range of (-π/2, π/2). In these figures, the horizontal axes represent the value of π/ $\Delta\beta$ in order to understand characteristics easily. The value of π/ $\Delta\beta$ means the number of prove-rings when the installation range is (-π/2, π/2). These figures show that estimation error becomes increase when the number of probe-rings decreases mostly depending on the value of the angle spread, $\sigma_\beta$. From these results, we find that the value of π/ $\Delta\beta$ should be equal to or larger than 12 when allowable error is 0.1 in the case of ($m_\beta$, $\sigma_\beta$) = (10 deg., 20 deg.). This means that required installation interval, $\Delta\beta$ is within 15 (=180/12) degrees.

## 4. Conclusions

We proposed the method to evaluate the performance of three-dimensional spatial channel emulator (or 3D-SCE) with respect to the spatial correlation characteristics. In our method, the three-dimensional probe antenna configuration is modelled by the vertical array of probe-rings, where the probe-ring is a ring of probe antennas circularly arrayed in horizontal plane. By using the model, the issue to evaluate the performance of 3D-SCE resolves itself by clarifying the impact of installation range and interval of probe-rings on the spatial correlation characteristics between reception points. When assuming the elevation power angular spectrum of Laplace distribution with mean angle-of-arrival of 10 degrees and angle spread of 20 degrees, these are typical values in urban macrocell propagation environment, the obtained results are as follows.

- The estimation error of spatial correlation becomes increase when the installation range is smaller or installation interval is larger.
- The characteristics of the estimation error mostly depend on the value of the elevation angle spread.
- The minimum of the required installation range is 68 degrees and the maximum of the required installation interval is 15 degrees when allowable error is 0.1. This means that the adequate number of probe-rings is 5 (> 4.53 = 68/15).

## References


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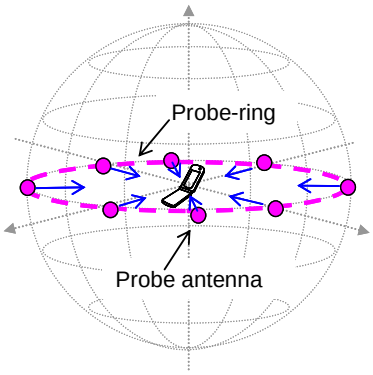



Figure 1: Probe antenna configuration in 2D- SCE.

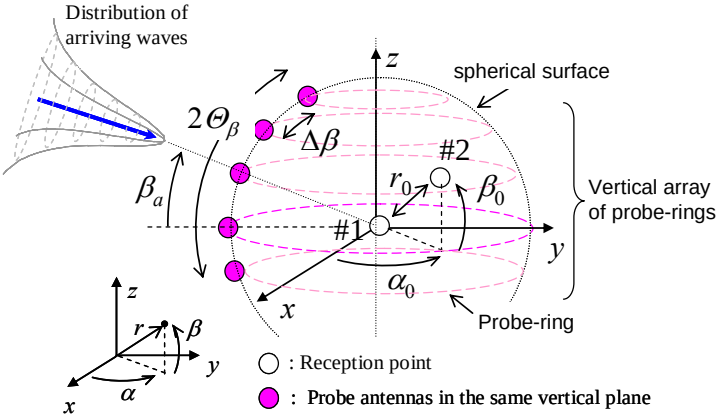
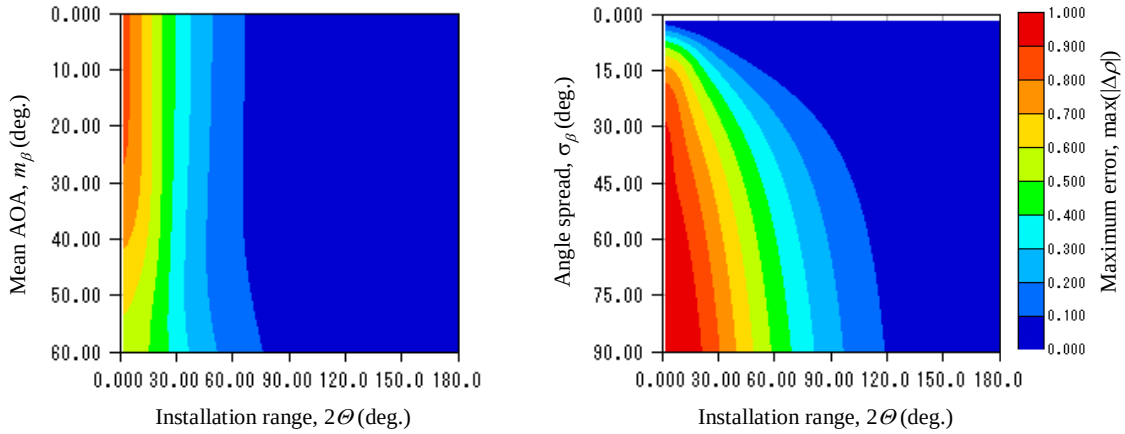
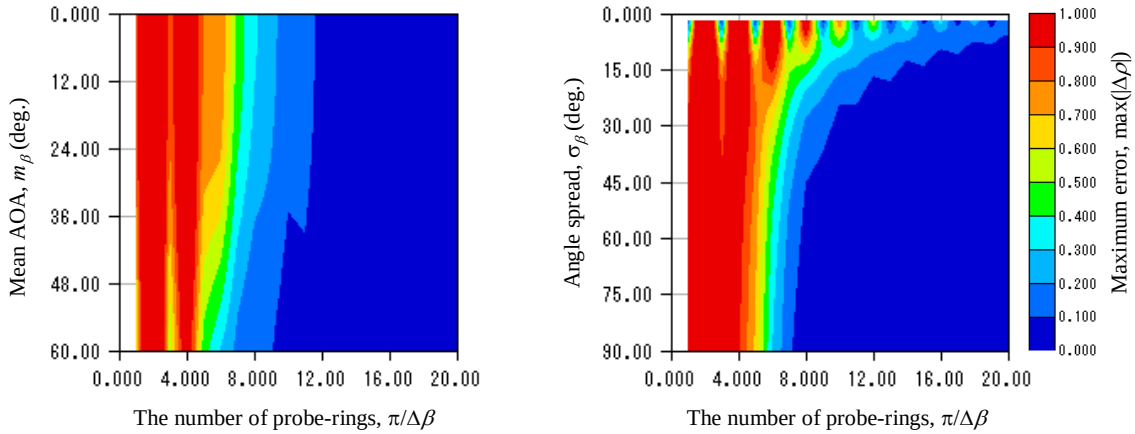



Figure 2: Evaluation model of 3D-SCE




(a) (b)

Figure 3: Relationship between installation range of probe-rings and estimation error when $\Delta\beta$=0.5 degrees, (a) that with mean angle-of -arrival as a parameter ($\sigma_\beta$=20 degrees), (b) that with angle spread as a parameter ($m_\beta$=10 degrees).




(a) (b)

Figure 4: Relationship between installation interval of probe-rings and estimation error when $2\Theta$=180 degrees, (a) that with mean angle-of -arrival as a parameter ($\sigma_\beta$=20degrees), (b) that with angle spread as a parameter ($m_\beta$=10degrees).