Modeling of Power Delay Profile in the Desktop Size Metal Cavity at 300 GHz

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***Abstract*—This paper proposes a two-dimensional (2D) geometrical propagation model for line-of-sight (LoS) communication in the desktop size metal cavity environment at 300 GHz. Based on the developed geometrical model, a parameter reference model and power delay profile (PDP) have been derived. The simulated PDPs have been compared with measured PDPs and good agreement has been observed.**

I. INTRODUCTION

Terahertz chip-to-chip wireless channel modeling inside a desktop computer requires understanding of the EM propagation mechanisms. For the modeling in free space, various models have been proposed [1]–[3]. The stochastic channel model based on ray-tracing has been proposed for the propagation channel of THz kiosk download application in [1]. The statistical channel model for THz indoor multipath fading channels has been proposed in [2]. The model for characterization of reflections from printed circuit board surface has been conducted in [3]. As compared to free space propagation, wireless propagation in the desktop like metal enclosure environment can have larger number of multiple reflections, which can introduce large multipath spread. Also, due to resonant nature of the fields in metal enclosure, the received power can vary with transceivers' positions [4]. A THz chip-to-chip wireless channel model in metal enclosures has been reported in [5] by considering resonant cavity effect.

In contrast, this paper proposes a 2D geometry based statistical model for LoS propagation of 300 GHz channel inside a desktop size metal enclosure. We first introduce a 2-D geometrical model. Using the geometrical model, a reference model has been proposed with the consideration of the signal's propagation mechanisms inside the metal cavity. Finally, we compare the simulated PDPs with measured data to verify the 2D reference model.

The remainder of the paper is organized as follows. Section II describes the geometrical model and a parametric reference model. Section III compares the simulated PDP results from the reference model with the measured data. Section IV provides concluding remarks.

II. GEOMETRY-BASED STATISTICAL MODEL

This section introduces geometry based statistical model for the propagation inside a desktop size metal enclosure. It is found from the 300 GHz channel measurements [4] that both traveling wave and resonant modes exist inside the cavity, and the traveling wave bounces back and forth between the transmitter (Tx) and receiver (Rx) positioned on the edges of the cavity. Therefore, we assume two dominate propagation mechanisms: 1) some waves travel directly from the Tx to the Rx, and 2) others reflect several times between the Tx and Rx before being received by the Rx. Figure 1 illustrates these propagation mechanisms inside the cavity. The model assumes that the M/Q ($M, Q > 1$) scatterers are uniformly distributed on the side walls of the cavity (where Tx/Rx are positioned), in a region bounded by the beamwidth of the antenna. Angles θ_T and θ_R denote the half-beamwidth of Tx and Rx antenna, while α_T^m and α_R^q represent the angle of departure and arrival, respectively. Since we assume that scatters are distributed uniformly, α_T^m and α_R^q can be expressed as $\alpha_T^m = -\theta_T + \frac{2(m-1)}{M-1}\theta_T$ and $\alpha_R^q = -\theta_R + \frac{2(q-1)}{Q-1}\theta_R$. The distance between Tx and Rx is equal to the length of the cavity, which is denoted by D. The symbols ϵ_T^m, ϵ_R^q, and ϵ_S^{mq} represent the distances of Tx - S^m, S^q - Rx, and $S^m - S^q$, respectively. Based on D, α_T^m, and α_R^q, the distances ϵ_T^m, ϵ_R^q, and ϵ_S^{mq} can be calculated as $\epsilon_T^m = \frac{D}{\cos\alpha_T^m}$, $\epsilon_R^q = \frac{D}{\cos\alpha_R^q}$, and $\epsilon_S^{mq} = \sqrt{|\epsilon_T^m \sin\alpha_T^m - \epsilon_R^q \sin\alpha_R^q|^2 + D^2}$.

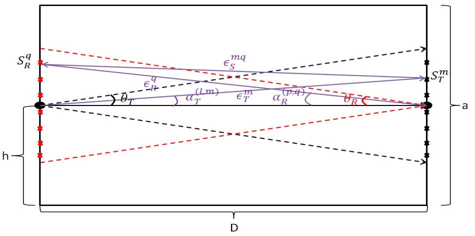

Fig. 1: The geometry-based statistical model for LoS propagation of 300 GHz wireless channel in the desktop size metal cavity environment.

From the geometrical model, the time-invariant input delay-spread function of the Tx - Rx link can be expressed as the superposition of the LoS and multi-bounced (MB) rays as follows

$$h(\tau) = h^{LoS}(\tau) + h^{MB}(\tau). \tag{1}$$

The LoS component of the input delay-spread function can be expressed as

$$h^{LoS}(\tau) = \sqrt{\frac{K}{K+1}} A_{LoS} e^{j\phi_{LoS}} \delta(\tau - \tau_{LoS}), \tag{2}$$

where K is the Ricean factor; $e^{j\phi_{LoS}} = e^{-jkD}$ represents LoS phase delay, where k is wave number and D is the length of

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the cavity; $\tau_{LoS} = \frac{D}{c}$ is the LoS time delay and c is the speed of light; A_{LoS} represents the LoS amplitude and can be written as $A_{LoS} = \sqrt{\frac{P_t G_t G_r}{PL}}$, where P_t, G_t, and G_r represent transmit power, transmit gain, and receive gain, respectively; PL is the path loss and can be calculated as

$$(PL^T)_{\text{dB}} = (\overline{\tilde{PL}})_{\text{dB}} + 10\log_{10}(|E|^2)^{-1}, \tag{3}$$

where $\overline{\tilde{PL}}$ represents the mean path loss of traveling wave and can be calculated by averaging Friis formula over the frequency band as $\overline{\tilde{PL}} = \frac{1}{\Delta f}\int_{\Delta f}\left(\frac{4\pi D\ f}{c}\right)^2 df$, where D represents the signal traveled distance. The parameter $10\log_{10}(|E|^2)^{-1}$ represents the received power variation contributed by resonating modes, where $|E|^2$ can be written as [6]

$$|E|^2 = |E_x|^2 + |E_y|^2 = |\sum_{n=1}^{N} E_{yn}|^2 + |\sum_{n=1}^{N} E_{xn}|^2. \tag{4}$$

EM field components E_{yn} and E_{xn} can be written as $E_{yn} = A_n \sin\left(n\pi h/a\right), E_{xn} = B_n \cos\left(n\pi h/a\right)$, where h is the antenna's height, and a is the height of the cavity. The value of A_n and B_n for $n = 1, 2, \ldots, N$ can be calculated using curve-fitting tools.

The multi-bounced component, $h^{MB}(\tau)$, of the input delay-spread function can be written as

$$\begin{aligned} h^{MB}(\tau) =& \sqrt{\frac{1}{K+1}} \frac{1}{\sqrt{LMQ}} \sum_{l=1}^{L}\sum_{m=1}^{M}\sum_{q=1}^{Q} \\ & A_{lmq} e^{j\phi_{lmq}} \delta(\tau - \tau_{lmq}), \end{aligned} \tag{5}$$

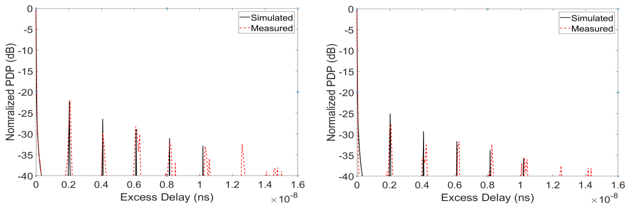
where L is the number of later arriving rays; ϕ_{lmq}, A_{lmq}, τ_{lmq} represent the phase, amplitude, and time delay of multipath components, respectively. The phase delay can be expressed as $-k \cdot (\epsilon_T^m + \epsilon_R^q + (2L-1)\epsilon^{avg})$, where $\epsilon^{avg} = \frac{1}{MQ}\sum_{m=1}^{M}\sum_{q=1}^{Q}\epsilon_S^{mq}$. The amplitude of the multipath component can be written as $A_{lmq} = \sqrt{\frac{P_t G_t G_r}{PL_{lmq}}} f(\alpha_T^m) f(\alpha_R^q)$, where PL_{lmq} can be calculated via equation (3) with traveling distance $d = \epsilon_T^m + \epsilon_R^q + (2L-1)\epsilon^{avg}$. Parameter $f(\psi)$ is the radiation pattern of the diagonal horn antenna with the form of $f(\psi) = X + Y cos(Z\psi)$. Finally, the time delay τ_{lmq} can be calculated as $\frac{\epsilon_T^m + \epsilon_R^q + (2L-1)\epsilon^{avg}}{c}$.

III. SIMULATED PDPS AND COMPARISON WITH MEASURED PDPS

In this section, we compare PDPs obtained using the proposed model with the PDPs obtained experimentally.

The measured data is collected at the frequency of 300 GHz with bandwidth of 12 GHz. The size of the metal cavity being used for the measurement is 30.5 cm×30.5 cm×9.6 cm. The transceiver's heights selected are (a)$h = 2.4$ cm and (b)$h = 1.2$ cm, respectively. The antenna being used in this measurement is a diagonal horn antenna whose gain varies between 22 dBi and 23 dBi with the half power beamwidths about 12°. We curve-fit the EM simulated radiation pattern (obtained by using CST v17) of the diagonal horn antenna. The parameters of the radiation pattern $f(\psi)$ are $X = 0.54$, $Y = 0.45$, and $Z = 11.15$.

Figures 2a and 2b compare the simulated and measured PDPs for two different transceiver heights $h = 2.4$ cm and 1.2 cm, respectively. The simulated PDP is obtained with the parameters $L = 5$, $M = Q = 45$, $K = 17.36$ and 33.04 for $h = 2.4$ cm and 1.2 cm, respectively. The Ricean factor K is estimated from the measurement using [7]. Due to the constructive/destructive interference of the fields at the receiver, the scattered power varies with the height. Hence, K differs for two heights.



(a) (b)

Fig. 2: The normalized measured and theoretical calculated PDP with (a) h=2.4 cm and (b) $h = 1.2$ cm.

Both PDP plots have several clusters of peaks that arrive with delay of 2.05 ns after the first arriving peak. This delay is the consequence of multiple bounces between the walls of the cavity where Tx and Rx are positioned. The simulated PDPs match well with the measured data. However, due to the assumption of lossless reflections (to simplify modeling), there are some discrepancies between the amplitudes of the simulated and measured PDPs.

IV. CONCLUSIONS

This paper presents a 2D geometric model for LoS propagation of 300 GHz channel inside a desktop size metal enclosure. Based on the geometrical model, a parameter reference model has been derived with superposition of the LoS and periodic multi-bounced rays. The reference model has been compared with the measurements and good agreement has been observed.

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