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# On the Realization Challenges for Accurate SCME Channel Implementation in RC

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## Abstract

This paper presents a discussion on theoretical solution for realizing accurate spatial channel model extension (SCME) in reverberation chamber (RC) and highlights the practical challenges on its implementations. For SCME to be correctly implemented in RC, the theoretical solution considers a reverse engineering approach, which requires an additional channel to be convoluted with the known RC channel. This additional channel could be divided into two parts, namely, the reference part and the delay-and-inverse part. This paper also presents the potential solutions in the realization.

## 1 Introduction

Accurate channel model implementation plays an import role for over-the-air (OTA) test for 4G (fourth generation) long-term revolution (LTE), 5G (fifth generation) new radio (NR) and emerging wireless communication devices, such as multiple-input-multiple-output (MIMO) [1–2]. To provide a level playing-field, channel emulation models like SCME (Extended Spatial Channel Model) [3] and Jakes [4] models can be used to mimic the multipath contribution from the real-world environment. Many different OTA test methods [1], [5]–[7] have been proposed, such as multi-probe anechoic chamber (MPAC) method, radiated two-stage (RTS) method, RC plus channel emulator (CE) method. Wireless industry groups like 3GPP (Third Generation Partnership Project) [1] and CTIA (International Association for the Wireless Telecommunication Industry) [6] have made significant afford researched into suitable MIMO OTA methods for standardization purposes.

SCME is the one of the most popularly used channel models in 3GPP for MIMO OTA testing of 4G LTE mobile user equipment (UE). It has been successfully employed in MPAC and RTS methods but its correct implementation in RC remains a key challenge. As depicted in the bottom diagram of Figure 1, the power delay profile (PDP) of an ideal SCME channel could be represented as several clustering of impulse taps. Its implementation in RC using CE presents trailing issues on each impulse tap, which is believed due to the inherent PDP of the RC with negative exponential profile [7]. Generally, it is envisaged that faster decay on the trailing on each impulse tap could be achieved with smaller chamber size and heavier chamber loading [8], [9], which could benefit towards accurate SCME implementation.

Using RC plus CE method, NIST has demonstrated that the SCME channel model could be implemented with heavy chamber loading within a small size RC where its relevant root-mean-square delay spread (RMS-DS) is about 90 ns. However, the use of these approaches would result in compromising the RC field uniformity as well as the available test zone. On the other hand, for large size RC, heavy chamber loading might not be feasible to decrease the RMS-DS from $\mu$s-level as for an empty RC to several tens of ns-level as for a loaded RC. The paper is organised as follow: Section 2 discuss the theoretical solution for realizing accurate SCME in RC, Section 3 highlights the practical challenges and presents the potential solutions in its realization, and finally, conclusions are drawn in Section 4.

## 2 Theoretical Solution for Accurate SCME Realization

As depicted in Figure 1, the basic idea for accurate SCME implementation in RC is to consider a reverse engineering approach by convoluting the known PDP of RC with a derived channel, X.

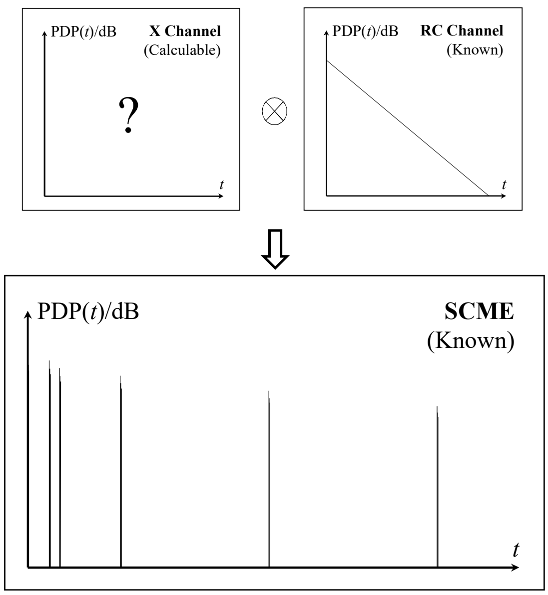


**Figure 1.** Basic idea of accurate SCME implementation in RC.

The following shows the relation between the relevant channels:

$$h^{X}(t) \otimes h^{RC}(t) = h^{SCME}(t) \quad (1)$$

where $h^{X}(t)$, $h^{RC}(t)$ and $h^{SCME}(t)$ are time domain transfer function of the X channel, RC channel and SCME respectively, and "$\otimes$" denotes the convolution. The X channel can be calculated by using

$$h^{X}(t) = \mathrm{Deconv}[h^{SCME}(t), h^{RC}(t)] \quad (2)$$

where "$\mathrm{Deconv}[h^{SCME}(t), h^{RC}(t)]$" means to deconvolve $h^{RC}(t)$ out of $h^{SCME}(t)$.

An illustrative diagram between the relevant channels is also presented in Figure 2. Note that Fig. 2(a) represents the 3GPP urban micro-cell SCME channel model [1] with clustering of 18 impulse taps. As depicted in Figs. 2(a) and 2(d), each impulse tap in the time domain transfer function of SCME was represented as a narrow Gaussian pulse with standard deviation of 0.1 ns. As shown in Fig. 2(b), RC channel was expressed by a time domain transfer function with a negative exponential profile. With a RMS-DS of 90 ns, the X channel could be correctly evaluated using Equation (2). Results can be seen in Figs. 2(c) and 2(e).

Note that a short negative time period (-10 ns to 0 ns) was considered for the first tap in SCME and X channel for numerical calculation. So that the negative half of the Gaussian pulse in the first tap will not missed. This will not lead to physical mistakes, instead it will simplify the analysis if the other taps were correct handled to get similar results like the results in the first tap. To investigate the effect on practical SCME implementation

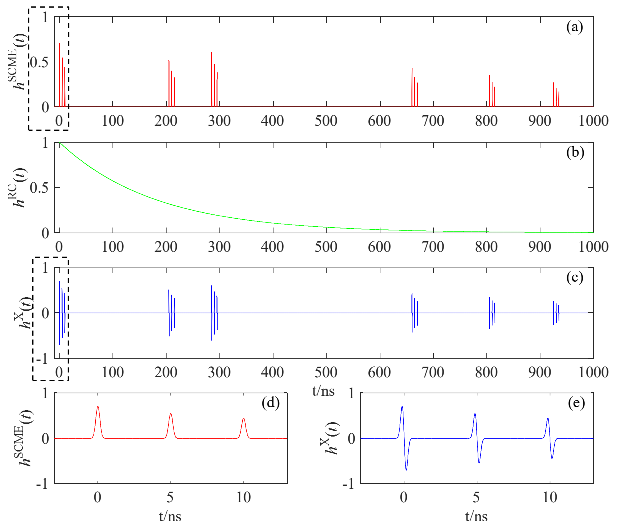


**Figure 2.** Theoretical time domain transfer function: (a) the whole SCME; (b) RC channel; (c) the whole X channel; (d) zoom in of SCME (for $t < 13$ ns) and (e) zoom in of X channel (for $t < 13$ ns).

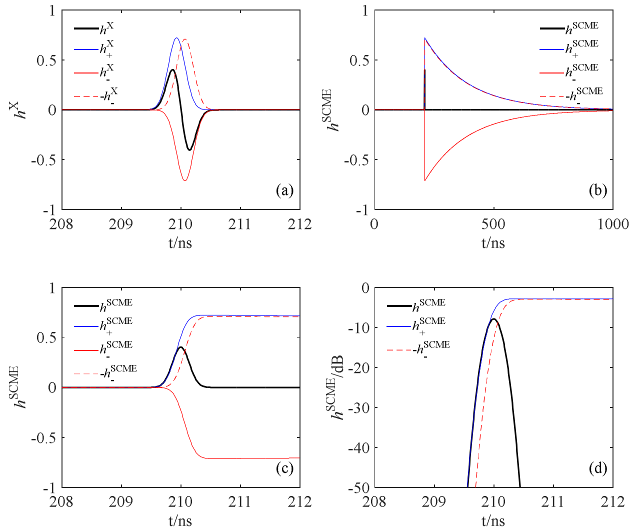


**Figure 3.** Time domain transfer function of an impulse tap: (a) X channel; (b) the whole SCME in linear; (c) part of SCME in linear (208 ns < $t$ < 212 ns) and (d) part of SCME in dB (208 ns < $t$ < 212 ns).

in RC, an impulse tap was considered (see Fig. 3). When necessary in future studies, this could be extended by considering all the impulse taps.

As depicted in Fig. 3, an example impulse tap was chosen at 210 ns with a relative power of –7.9 dB (according to the definition of the 3GPP urban micro-cell SCME channel model). The X channel can be decomposed into two parts as

$$h^{X}(t) = h_{+}^{X}(t) + h_{-}^{X}(t) \quad (3)$$

where $h_{+}^{X}(t)$ is the positive part of $h^{X}(t)$, and $h_{-}^{X}(t)$ is the negative part. These two parts convolve with RC channel, and will turn into positive and negative part of SCME respectively, as

$$h_{+}^{X}(t) \otimes h^{RC}(t) = h_{+}^{SCME}(t) \quad (4)$$

$$h_{-}^{X}(t) \otimes h^{RC}(t) = h_{-}^{SCME}(t) \quad (5)$$

$$h^{SCME}(t) = h_{+}^{SCME}(t) + h_{-}^{SCME}(t) \quad (6)$$

where $h_{+}^{SCME}(t)$ is the positive part of $h^{SCME}(t)$, and $h_{-}^{SCME}(t)$ is the negative part.

As shown in Figs. 3(a) and 3(c), $h_{+}^{X}(t)$ has Gaussian pulse shape, with different amplitude but same width with the tap of SCME. Meanwhile, $h_{-}^{X}(t)$ is a small delay ($\Delta t$) and inverse of $h_{+}^{X}(t)$. This $\Delta t$ makes the $h_{-}^{SCME}(t)$ has the same delay with $h_{+}^{SCME}(t)$, and the inverse makes $h_{-}^{SCME}(t)$ is opposite with $h_{+}^{SCME}(t)$ in $h_{-}^{SCME}(t)$'s trailing period. Then as shown in Figs. 3 (b) and 3(d), most of the trailing of $h_{+}^{SCME}(t)$ has been offset with $h_{-}^{SCME}(t)$, and the residual result in the early small time period of $h_{+}^{SCME}(t)$ is to be the SCME tap aimed. It is noted that this offset and residual phenomenal are important factors for accurate SCME implementation.

The above negative values in time domain transfer functions do not exist in real life. For any time-domain transfer function, its values are always non-negative. In this paper, the negative means a relative relation between two components in the same function, for example between $h_+^{\mathrm{X}}(t)$ and $h_-^{\mathrm{X}}(t)$, or between $h_+^{\mathrm{SCME}}(t)$ and $h_-^{\mathrm{SCME}}(t)$. The offsets shown by Fig. 3 are introduced by this negative. Furthermore, this negative could also be explained by frequency domain transfer functions as

$$H_+(\omega)=A(\omega)\exp[i\varphi(\omega)] \tag{7}$$

$$H_-(\omega)=A(\omega)\exp[i\varphi(\omega)+i\pi] \tag{8}$$

where $H_+(\omega)$ and $H_-(\omega)$ are corresponding frequency domain transfer functions of two negative time domain transfer functions. In frequency domain, this negative could be explained by a phase difference ($\Delta\varphi$) of 180°. Feature of this negative is the offset for transfer functions as

$$\begin{aligned} &H_+(\omega)+ H_-(\omega) \\ &=A(\omega)\exp[i\varphi(\omega)]+A(\omega)\exp[i\varphi(\omega)+i\pi]=0 \end{aligned} \tag{9}$$

In general, based on the additional channel explained above, accurate SCME could be implemented in theory, and the key feature of the additional channel is the offset and residual phenomenal introduced by delay and negative relationship between two components in the channel. The above accurate SCME implementation solution is similar with that in [3]. But comparing with [3], there are two main differences. The first is that the basic form of each tap of SCME is a narrow width Gaussian pulse in this paper but an ideal unit impulse in [4], this makes the results in this paper much closer to real life. The second is that the reason for the SCME implementation has been further explained by the offset and residual phenomenal and the negative relationship in theory. The other difference between this paper and [4] will be explained in the future work.

## 3 Challenges and Potential Solutions in Accurate SCME Realization

Figure 4 provides an illustration on how accurate SCME could be realized in practice. According to the above theoretical study, the SCME taps are defined by CE as the positive component of $h^{\mathrm{X}}(t)$. Then there is a reference path and a delay and inverse path divided after the CE. Comparing with the reference path, additional delay line and phase shifter are applied in the delay and inverse path.

Function of delay line and phase shifter is to make that there is a certain delay ($\Delta t$) and phase difference ($\Delta\varphi=\pi$) between these two paths before their combination. Integration of SCME by CE and the reference path is the channel of $h_+^{\mathrm{X}}(t)$, and in the same time integration of SCME by CE and the delay and inverse path is the channel of $h_-^{\mathrm{X}}(t)$. Then $h^{\mathrm{X}}(t)$ is designed by the part shown

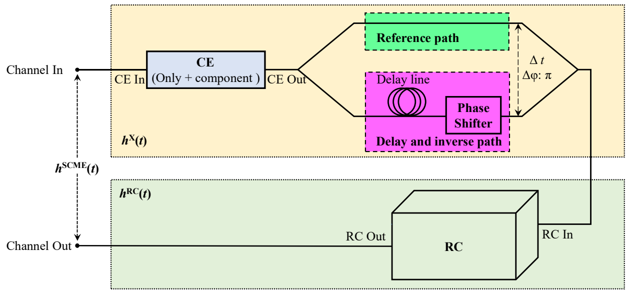


**Figure 4.** Realized the accurate SCME implementation theory by block diagram experiment.

as the upper dashed box in Fig. 4. Totally, the $h^{\mathrm{X}}(t)$ part was applied to RC, and SCME are assumed to be implemented in the chamber. But the delay line in physical may lead to certain group delay besides the absolute delay, then the phase difference before the combination is not a constant in the whole channel frequency band, also not a constant of π as designed. Then this group delay introduced by delay line will result in the failure of the implementation. In detail, if longer coaxial cable as used as delay line, the absolute delay and corresponding group delay will be

$$\Delta t_{\text{delay-line}}=L_e/c \tag{10}$$

$$\Delta G_{\text{delay-line}}=-\partial\varphi/\partial\omega=\Delta t_{\text{delay-line}} \tag{11}$$

where $\Delta t_{\text{delay-line}}$ is the absolute delay introduced by the coaxial cable as delay line, $L_e$ is electoral length of the cable, $c$ is light speed in a vacuum, $\Delta G_{\text{delay-line}}$ is the group delay introduced by the absolute delay, $\varphi$ is the phase in the channel frequency band and $\omega$ is radian frequency. Caused by this group delay, the negative components shown as (8) will a different value in experiment as

$$H_-(\omega) = A(\omega)\exp[\mathrm{i}\varphi(\omega)+i\pi+i(\omega-\omega_0)\Delta t_{\text{delay-line}}] \tag{12}$$

where $\omega_0$ is a constant radian frequency with zero phase shift. The longer of $L_e$, the acuter of the phase difference will be envisaged. As the general results shown by (10) – (12), the offset shown as (9) will not appear. In the other words, group delay introduced by delay line is the key challenge for ideal SCME implementation in RC.

One possible solution for this challenge is to use delay line with absolute delay but zero group delay. The usual delay lines such as coaxial cable always lead to positive group delay. So negative group delay components added to the usual delay line maybe a solution to realize a combiner delay line with absolute delay but zero group delay. Then the negative group delay component should have a negative and constant group delay in the whole frequency band of channel, and the constant should be exactly the negative of group delay of usual delay line. The other possible solution is to use modified CE. If a CE could add a phase shift array (a sequence value for different frequency points) to the emulated channel with certainty delay (maybe by software define method), absolute delay but zero group delay could also be realized to solve the challenge.

## 4 Conclusion

In this paper, a discussion on the theoretical solution for realizing accurate SCME channel in RC has been presented as well as the highlights on the practical challenges and the potential solutions in its realization. With the help of these solutions, OTA measurement results in RC could be more comparable with the other potential test 5G OTA methods, such as MPAC and RTS.

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