SCME true PDP emulation using a channel emulator and a mode-stirred reverberation chamber

García-Fernández, Miguel Á and Sánchez-Hernández, David A., Senior Member, IEEE

Abstract—A mode-stirred reverberation chamber emulates a channel model that has an innate exponential decay power delay profile (PDP). In this contribution, we propose a novel method to emulate a Spatial-Channel-Model-Extended (SCME) when a channel emulator (CE) is used in combination to a reverberation chamber (RC). The novel technique deconvolves the innate exponential decay PDP of the RC out of the desired channel model in order to obtain the delay taps to be injected into the CE+RC to emulate the desired SCME true PDP. Results show for the first time that accurate SCME true PDP emulation can be performed with a channel emulator connected to a reverberation chamber.

Index Terms—MIMO OTA, Reverberation Chamber

I. INTRODUCTION

A mode-stirred reverberation chamber (MSRC) emulates a channel model that has an innate exponential decay power delay profile (PDP). A reverberation chamber can also be tuned to change its PDP RMS delay spreads (RMS DS) using loading absorbers, to the one of a channel model known as NIST Indoor-Urban, which is based on real outdoor-to-indoor channel measurements in urban environments. Also, it can be useful to emulate the 3GPP standardized Urban Macro-cell (UMA) and Urban Micro-cell (UMI) Spatial Channel Model Extended (SCME) for the 3GPP/CTIA/COST2100 HSDPA SIMO round robin campaign using a reverberation chamber, as described in [3]. The employed technique consisted on injecting a SCME channel model emulated by a channel emulator (CE) using different delay taps onto an RC which was previously tuned to have a small RMS DS of 90 ns, as the NIST Indoor-Urban channel model PDP. Testing was performed using step-wise stirring, wherein the throughput was sampled at each fixed stirrer position to avoid any Doppler shift. The SCME UMA and UMI power delay profiles are illustrated in figure 1, as specified in [3]. For the HSDPA SIMO OTA round robin, the employed SCME UMI and UMA setups for the channel emulator were those defined in 3GPP TR 37.976 [4].

Yet, the emulated PDP resulted in that of the SCME convolved with the MSRC PDP, which was found to provide final throughput values different from those emulated by anechoic chamber methods. Since the SCME emulation of anechoic-based OTA methods suffer from a number of flaws, it was not concluded along the 3GPP/CTIA/COST2100 HSDPA SIMO round robin campaign whether the final throughput of SIMO OTA using injected SCME models in a reverberation chamber was more or less accurate than those

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results obtained with anechoic-based methods, but simply that the two methods exhibit different results. Similarly, several authors have highlighted that the use of uniform models (like the NIST Indoor-Urban channel model) are more appropriate than multiple-cluster or geometrical models (like SCME) to test MIMO devices using OTA techniques. The suitability of a specific channel model for MIMO OTA testing is still a subject of discussion on both 3GPP and CTIA, and it is not the subject of the present contribution. In this contribution, we propose a novel method to emulate SCME true PDP when a channel emulator is used in combination to a mode-stirred reverberation chamber. The novel technique deconvolves the innate exponential decay PDP of the RC out of the desired channel model in order to obtain the delay taps to be injected into the CE+RC to emulate the desired SCME true PDP. Results show that accurate SCME true PDP emulation can be performed with a channel emulator connected to a reverberation chamber. The technique has been employed in the 3GPP LTE MIMO OTA round robin campaign.

II. CHANNEL EMULATION IN A MODE-STIRRED REVERBERATION CHAMBER

An MSRC can be tuned (using loading absorbers) to emulate a NIST Indoor-Urban channel model. A summary of parameters describing the NIST channel model is displayed in Tables I and II. Table II gives the corresponding taps for a tapped delay line channel would it be implemented in a channel emulator, as specified in CTIA RCSG HSDPA SIMO RR Test Plan [3].

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<thead>
<tr>
<th>TABLE I</th>
<th>NIST INDOOR-URBAN CHANNEL MODEL SUMMARY</th>
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<tbody>
<tr>
<td>700-2700</td>
<td>90</td>
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<tr>
<th>TABLE II</th>
<th>INDOOR-URBAN DELAY MODEL</th>
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<tbody>
<tr>
<td>Delay Window 90% Energy [ns]</td>
<td>Delay Interval 25 dB [ns]</td>
</tr>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>40</td>
<td>-1.7</td>
</tr>
<tr>
<td>120</td>
<td>-5.2</td>
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<tr>
<td>180</td>
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<tr>
<td>210</td>
<td>-9.1</td>
</tr>
<tr>
<td>260</td>
<td>-11.3</td>
</tr>
<tr>
<td>350</td>
<td>-15.2</td>
</tr>
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</table>

The NIST Indoor-Urban channel model PDP emulated by an MSRC can be measured by the direct method where the frequency response of the chamber is Fourier transformed to the time domain. The calculation of RMS delay spread is performed on the time domain data. This can be done directly by calculating the standard deviation of the PDP, which does not account for potential sources of errors in the windowed frequency response of the antenna, or finding out the relationship between RMS DS and the slope of the PDP. Given this relationship, we can estimate the RMS DS from a measurement of the frequency response of the chamber, which is measured during the chamber calibration procedure, in order to obtain the average power transfer function in the chamber. The relationship between RMS DS (στ), and the frequency response of the channel Hch is given by

\[ \sigma_t = \frac{10}{\ln 10} \frac{1}{m} \frac{d}{dt} |h(t)| = 2 \frac{d}{dt} \text{IFFT}(H_{ch}) \]

where \( m \) stands for the slope of the PDP (in dB) as a function of the time, \( t \); \( h(t) \) is the impulse response function (IRF) of the chamber; and IFFT is the Inverse Fast Fourier Transform. It is worthy to note that the relationship between the frequency response of the chamber \( H_{ch} = S_{21} \) and the average power transfer function of the chamber \( G_{ch} \) is given by

\[ G_{ch} = \frac{\langle |S_{21}|^2 \rangle}{\langle 1 - \langle |S_{11}|^2 \rangle - \langle |S_{22}|^2 \rangle \rangle} \]

where \( \langle \ldots \rangle \) is the arithmetic mean. Figure 2 depicts the measured NIST Indoor-Urban channel model PDP of the E300 Mode-Stirred Reverberation Chamber tuned for an RMS DS of 90±5 ns as specified in the CTIA Test Plan for HSDPA SIMO RR. The E300 MIMO Analyzer is a second generation two-cavity mode stirred reverberation chamber with external dimensions of 0.82m x 1.425m x 1.95m, 8 exciting antennas, polarization stirring due to aperture-coupling and to the different orientation of the antenna exciting elements, 3 mechanical and mode-coupling stirrers, 1 holder-stirrer and variable iris coupling. The theoretical 90±5 ns RMS DS NIST Indoor-Urban channel model approximated with 7 taps is also depicted in figure 2 for comparison purposes.

III. SCME CHANNEL EMULATION IN 3GPP HSDPA SIMO OTA ROUND ROBIN USING REVERBERATION CHAMBER

The channel model emulated within a reverberation chamber for the combined RC+CE candidate methodology performed within 3GPP HSDPA SIMO RR is that of the SCME setup in a CE convolved to a the exponential decay PDP channel model which is innate to the RC. This is illustrated in figure 3 for the theoretical SCME UMA 6 taps channel model and the MSCE tuned (using loading absorbers) to emulate a NIST Indoor-Urban channel model, that is, its innate exponential decay PDP but with a RMS delay spread of 90±5 ns.
This clearly is different from the PDP of SCME UMI and UMA channel models which are shown in Figure 1. The exponential decay effect seen on each tap could adversely affect the throughput performance of the DUT.

IV. ACCURATE SCME TRUE PDP CHANNEL EMULATION IN A MODE-STIRRED REVERBERATION CHAMBER

The emulation of an SCME channel model within an MSRC using a RC+CE candidate methodology could be more accurately done by calculating the delay taps required in a channel emulator that should be injected in practice into an MSRC with a small RMS DS PDP, as the NIST Indoor-Urban channel model PDP, in order to obtain the desired SCME within the MSRC. This is obtained by deconvolving the innate exponential decay PDP of the MSRC out of the desired SCME PDP to be emulated. The resulting PDP has to be translated into delay taps to be set up in the channel emulator. The result of this deconvolution is shown in figure 4.

The bottom graphic at figure 4 depicts the PDP that should be available at the output of the channel emulator to obtain the desired SCME UMA 6 taps emulated within the E300 chamber. This graphic shows some taps with 0º phase and some other taps with 180º phase, slightly delayed to the first ones. When adding two similar figures with opposite sign and an infinitesimal time difference, instead of zero, a Dirac delta with the amplitude equal to that of the exponential is obtained. When a very minute time has passed, the exponential has decayed an amplitude equal to $e^{-\tau_{rms}/\delta}$, where $\tau_{rms}$ is the RMS DS, and therefore the negative delta counterpart of a positive delta should be of that amplitude in order to obtained exact amplitude results in the deconvolution. This is demonstrated by figure 5, wherein the delay taps required in a channel emulator (top) are theoretically injected into an MSRC with the 90±5 ns RMS DS NIST channel model (medium), and the resulting emulated channel model is given (bottom). The theoretical SCME UMA 6-taps is compared to this output in figure 6. As it can be observed, the proposed emulated SCME UMA closely follows the theoretical SCME UMA 6-taps.
Fig. 5. The delay taps required in a channel emulator (top) that should be injected in practice into an MSRC with a small RMS DS, as the NIST Indoor-Urban channel model PDP, (medium) in order to obtain the desired theoretical SCME UMA 6 taps emulated inside the RC (bottom).

Table III

<table>
<thead>
<tr>
<th>Excess tap delay [ms]</th>
<th>Relative power [dB]</th>
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<tr>
<td></td>
<td>-0.2527</td>
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<tr>
<td></td>
<td>-0.2528</td>
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<tr>
<td></td>
<td>0.36</td>
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<tr>
<td></td>
<td>0.3601</td>
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<tr>
<td></td>
<td>1.0387</td>
</tr>
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<td>1.0388</td>
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</tr>
<tr>
<td></td>
<td>4.5977</td>
</tr>
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<td></td>
<td>4.5978</td>
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Table 1 requires some degree of accuracy in the amplitude of the taps. Alternatively, since $e^{-\omega_i t_{\text{rms}}}$ tends to zero when $\delta t$ tends to zero, and since $\delta t$ is an infinitesimal time value, the technique could also perform in a satisfactory manner if the innate RMS DS of the RC is assumed to have a fixed value (i.e. 90 ns). In this case, it would be enough to add, for each tap delay in the SCME to be emulated, a counterpart negative tap delayed an infinitesimal amount of time. For some commonly used CEs, this would be $\delta t(t) = 0.1$ ns, for which $e^{-\omega_i t_{\text{rms}}} = 0.9989$, taking $t_{\text{rms}} = \text{RMS DS} = 90$ ns.

V. CONCLUSION

Accurate emulation of SCME true PDP is proposed for a channel emulator connected to a mode-stirred reverberation chamber for the first time. Regardless of the accuracy that SCME represents to reproduce a realistic scenario, or whether the uniform channel model could be also use for MIMO OTA tests, this SCME true PDP emulation using a reverberation chamber could be very useful for future MIMO OTA studies. 3GPP and CTIA, in particular, could clearly benefit from comparable results to other candidate methodologies.

REFERENCES


Miguel Á. García-Fernández was born in Cartagena, Spain. He received the Dipl.-Ing. in Telecommunications Engineering from Universidad Politécnica de Cartagena, Spain, in July 2005 and his Ph.D. from Universidad Politécnica de Cartagena, Spain, in January 2010. In November 2005 he joined the Department of Information Technologies and Communications, Universidad Politécnica de Cartagena, Spain. In October 2009 he also joined the Department of Applied Mathematics and Statistics, Universidad Politécnica de Cartagena, Spain. His current research areas cover multiple-input–multiple-output communications, SAR measurements and thermoregulatory processes due to electromagnetic field exposure.

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