



UNIVERSITÀ POLITECNICA DELLE MARCHE
Repository ISTITUZIONALE

Rician K Factor Tuning for 5G Channel Emulation in Different Typologies of Reverberation Chambers

This is the peer reviewed version of the following article:

Original

Rician K Factor Tuning for 5G Channel Emulation in Different Typologies of Reverberation Chambers / De Leo, A.; Serra, R.; Russo, P.; Primiani, V. M.. - ELETTRONICO. - (2023). (2023 International Symposium on Electromagnetic Compatibility - EMC Europe, EMC Europe 2023 Cracovia 4 - 8 September 2023) [10.1109/EMCEurope57790.2023.10274408].

Availability:

This version is available at: 11566/323611 since: 2025-11-19T12:19:58Z

Publisher:

Institute of Electrical and Electronics Engineers Inc.

Published

DOI:10.1109/EMCEurope57790.2023.10274408

Terms of use:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. The use of copyrighted works requires the consent of the rights' holder (author or publisher). Works made available under a Creative Commons license or a Publisher's custom-made license can be used according to the terms and conditions contained therein. See editor's website for further information and terms and conditions.

This item was downloaded from IRIS Università Politecnica delle Marche (<https://iris.univpm.it>). When citing, please refer to the published version.

Publisher copyright:

IEEE - Postprint/Author's Accepted Manuscript

©2023 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. To access the final edited and published work see 10.1109/EMCEurope57790.2023.10274408

(Article begins on next page)

Rician K Factor Tuning for 5G Channel Emulation in Different Typologies of Reverberation Chambers

Alfredo De Leo

Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
a.deleo@univpm.it

Ramiro Serra

Department of Electrical Engineering
Eindhoven University of Technology
Eindhoven, The Netherlands
r.serra@tue.nl

Paola Russo

Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
paola.russo@univpm.it

Valter Mariani Primiani

Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
v.mariani@univpm.it

Abstract— Reverberation chambers usually exhibit low values of the Rician k factor; this means that the stirred component of the electromagnetic field is dominant with respect to the unstirred one. To increase this parameter in order to emulate propagation environments for 5G telecommunication systems, usually lossy elements are added into the chamber. In this way, the strength of the field inside the cavity decreases and more amplification of the signal is needed. This paper shows how to increase the Rician k factor by selecting a subset of electromagnetic configurations without the insertion of dissipative material. Successful results were obtained using different typologies of stirring techniques, multiple monopole source stirring, rotating paddles mechanical stirring, and oscillating wall stirring.

Keywords: 5G new radio; reverberation chamber; Rician K factor; statistical analysis.

I. INTRODUCTION

5G is the new generation of the global telecommunications network and represents an evolution in terms of performance compared to previous generations, integrating the latter progress in the ICT area [1] – [3].

The main novelty aspects concerning the previous generation of communication systems are related to the transmission speed of up to 1 Gbps, the density of users served by geographical areas of up to one million connected devices per km², and the communication delays of up to only 1 ms.

On the other hand, 5G enables the realization of varied application scenarios that before was not possible to achieve with a single type of network.

With the 5G network, it is now possible to implement high reliability and low delay communications, to interconnect many sensors and actuators in a small physical space, and to provide high-speed and high-density communications.

There is a consensus that 5G needs low bands for coverage, medium bands for faster speeds covering a reasonable area and high-frequency bands for the highest speeds. Currently, the most used bands are [4]:

- Low-band: lower than 1 GHz;
- Mid-band: 1 to 6 GHz;
- High-band: 24 to 40 GHz.

The new characteristics and potentialities of 5G systems also pose an additional challenge to the over-the-air tests performed to assess the performance of such systems. One prominent example of a flexible and convenient environment to perform such measurements is the reverberation chamber (RC).

Propagation environments for 5G communication systems can be characterized by values of Rician K-factor (K) on the order of some units [5] – [9], while Reverberation Chambers (RCs) have usually lower K values [10] – [11], because the stirred component of the electromagnetic field should be greater than the unstirred one to have good performances.

In order to increase K, usually lossy elements are inserted into the RC, but in this way also the quality factor of the chamber decreases, and more amplification is needed to achieve the same level of the electromagnetic field inside the RC.

Recently [12] a novel algorithm has been proposed to increase the value of K without the need to increase losses. The algorithm is based on the selection of the electromagnetic field configurations, and it was demonstrated on a Multiple Monopole Source Stirred (MMSS) RC. In [12], it was claimed that the algorithm can be applied in theory on any RC where the stir states are repeatable.

At this scope in this paper the method was applied to three different typologies of RC: a Mechanical Stirred (MS) RC, an Oscillating Wall Stirred (OWS) RC, and a MMSS RC.

The method and the Scenarios will be described in Section II and III respectively, whereas effectiveness of the method and comparison among the result will be discussed in section IV. Finally, conclusions will be discussed.

II. THE METHOD

The method [12] to increase the value of the Rician K-factor is here briefly reported for sake of completeness.

It is based on the definition of K [10] as the ratio between the direct and the scattered component of the power, according to (1).

$$K = \frac{(|\langle S_{21} \rangle|)^2}{\langle |S_{21} - \langle S_{21} \rangle|^2 \rangle} \quad (1)$$

where $\langle \cdot \rangle$ means the average over all the samples.

Usually, RCs have values of K lower than the propagation environment of the 5G communication systems. If we want to increase K to reach the desired value K^* , we must increase the numerator and decrease the denominator of (1).

Let us consider the scatter plot of the S_{21} parameter related to N realizations of the chamber, defined as the transmission coefficient between the transmitting antenna and the receiving one (S_{21}). The K is the ratio between the square of their average and their covariance.

If we want to select a subset of M S_{21} values having a greater K than the overall realizations, we must choose among those elements whose, in the complex plane, have the S_{21} value distant from the origin of the axis and that are, at the same time, close to each other.

In order to achieve the desired value of K , we define a normalized distance $dist(i, k)$ as the ratio e between the distance of the k -th element from the i -th one and distance of the i -th element from the origin of the axis in the complex plane.

$$dist(i, k) = \frac{|S_{21}^{(i)} - S_{21}^{(k)}|}{|S_{21}^{(i)}|}, \quad (2)$$

For each i -th element it can be defined a subset S_{21} values that contains all the elements having a normalized distance lower than a reference normalized distance $dist_{MAX}$. The lower is $dist_{MAX}$, the higher is the corresponding value of the Rician K factor.

We decrease the value of $dist_{MAX}$ until we reach the desired value of K^* . Among all the subsets of S_{21} values that have a K factor greater than K^* , the most populated is chosen.

More detail on the algorithm can be found in [12].

III. SCENARIO

In this section the scenarios where the method was applied are described: a multiple monopole source stirred RC, a RC with one mechanical stirrer, and an oscillating wall stirred RC. In all these scenarios the goal of the method is to increase the Rician K factor over the threshold of $K^*=7$ over all the considered frequency ranges.

A. Multiple Monopole Source Stirred RC

The Multiple Monopole Source Stirred RC is a facility of the Università Politecnica delle Marche. It is a rectangular cavity made of galvanized steel, having dimensions $0.8 \text{ m} \times 0.9 \text{ m} \times 1.0 \text{ m}$. The stirring action is achieved by inserting a monopole antenna sequentially in each of the 120 holes present in its walls (20 holes in each face), as shown in Fig. 1. Its first resonant mode is 225 MHz, and it has been investigated theoretically [13], numerically [14] and experimentally [15] in the frequency range 675 MHz – 6 GHz.



Fig.1. Monopole manually inserted into one of the holes of the chamber to achieve the Multiple Monopole Source Stirring action.

The Rician K factor value of the empty MMSS RC is reported in Fig. 2.

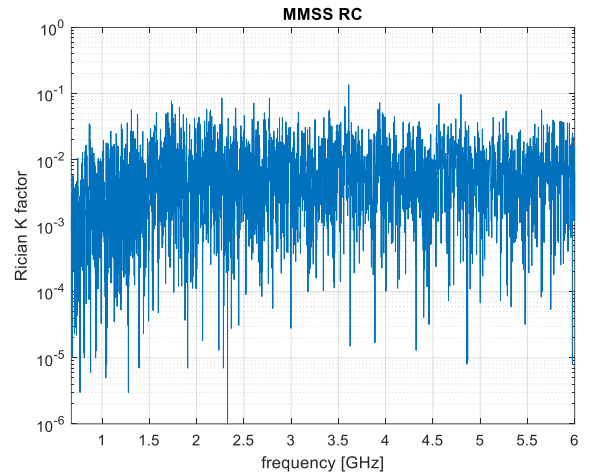


Fig.2. Rician K factor of the MMSS RC in the frequency range 1-6 GHz

B. Mechanical Stirred RC

The same chamber can be equipped with the mechanical stirring technique, rotating a Z-folded metallic paddle, as shown in Fig. 3. The stirrer was rotated by 3° for a total of 120 stirrer positions.



Fig.3. Z-folded metallic stirrer used to achieve the Mechanical Stirring action.

The measured Rician K-factor is reported in Fig. 4. As already highlighted in [15], the K value in the same cavity is higher using the MS rather than using the MMSS technique, especially in the lower frequency range. This happens since in the MS the stirrer becomes short in terms of wavelength, while in MMSS varying the position of the transmitting antenna, it is possible to stir also the quasi-static component of the electromagnetic cavity, dominant at lower frequencies.

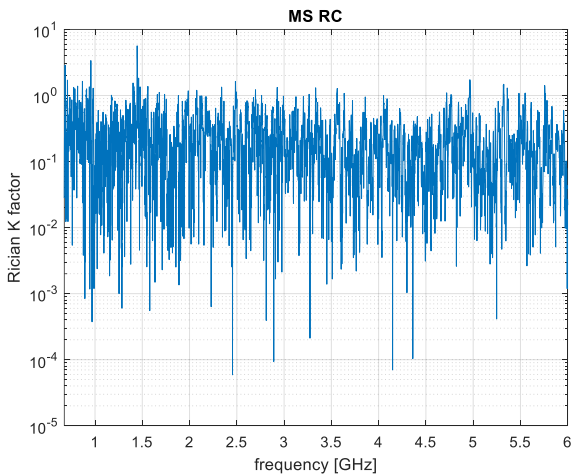


Fig.4. Rician K factor of the MS RC in the frequency range 1-6 GHz

C. Oscillating Wall Stirred RC

The OWS RC (Fig. 5) is a facility of the Eindhoven University of Technology (TU/e) and has the dimensions $4.05 \text{ m} \times 5.7 \text{ m} \times 3.15 \text{ m}$ (h).

This stirrer belongs to the class of mechanic mode stirrers, and it is conceived as an interior metallic scatterer featuring a complex geometry of a considerable size. Nevertheless, it differs from most stirrers in the fact that it does not rotate, but instead it oscillates. The modal structure in the RC is then significantly perturbed by such movement thus achieving, in the overmoded regime, statistical field uniformity.

More details on this OWS RC and on its performances can be found in [16], [17].



Fig.5. The Oscillating Wall Stirred Reverberation Chamber

The measured Rician K-factor is reported in Fig. 6. This room-sized chamber has dimensions larger than the MMSS / MS RC described in the previous subsections, hence it was investigated in a lower frequency range, from 100 MHz to 2 GHz.

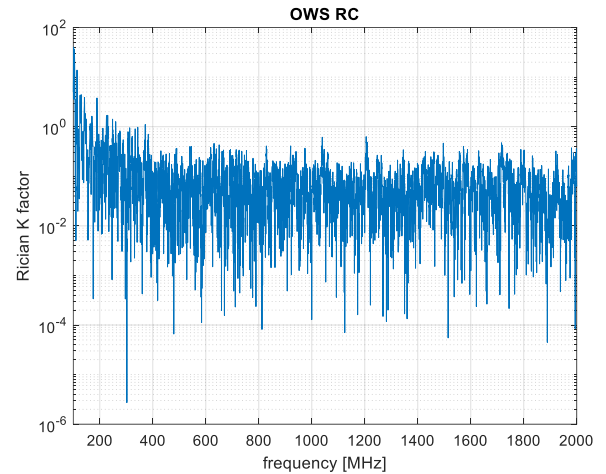


Fig.6. Rician K factor of the OWS RC in the frequency range 0.1-2 GHz

IV. RESULTS

In this section, the results obtained using the proposed method in all the considered scenarios are described. The goal was to increase the Rician K factor to values greater than 7, thus emulating a realistic propagation environment.

Two frequency bands reserved for 5G data transmission are investigated. In particular, the band between 731 and 778 MHz has been chosen in the low band range for all the three considered chambers. As regards the mid band range, the MMSS and the MS RC were investigated between 3.27 and 3.80 GHz, used in Italy for data Frequency Division Duplex (FDD) uplink and downlink [18]. The OWS RC was investigated in the frequency range between 1920 and 1980 MHz, used for the UL 2100 (Supplementary Uplink) [19].

A. Multiple Monopole Source Stirred RC

The method has been applied to the MMSS for enhancing the K-factor within the bandwidth 731 – 778 MHz and 3270

– 3800 MHz. To highlight the algorithm effect, Fig. 7 shows the scatter plot of all the measured S_{21} values and of the subset selected by the proposed method for the frequency of 755 MHz when it is imposed that the Rician K factor should be greater than 7. The number of configurations reduces to 23 in this case and the obtained K-factor is equal to 7.0252.

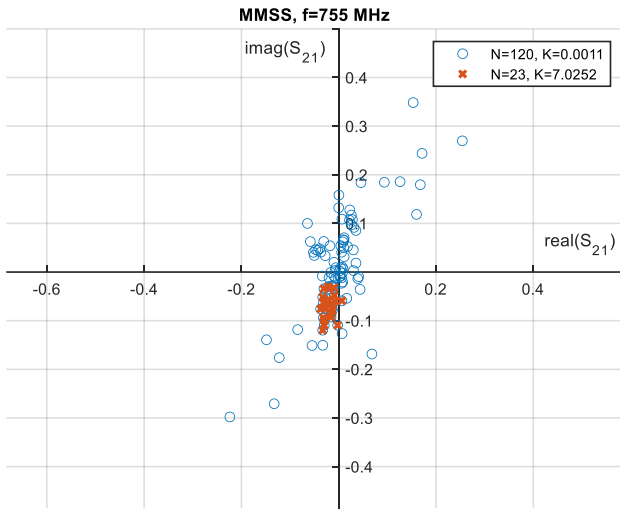


Fig.7. Scatter plot of all the measured S_{21} values and of the subset returned by the proposed method to have $K^*>7$.

Considering the overall results of the application of the algorithm, Figs. 8 and 9 show the obtained K factor in the band 731 – 778 MHz and 3270 – 3800 MHz respectively. In both cases the proposed algorithm works successfully, and the Rician K factor is greater than 7 in all the frequency range. From figures 8 and 9, it can also be seen the number of configurations selected by the algorithm for all the frequencies. They vary from 10 to 40 in the lower frequency range and from 12 to 25 in the higher frequency range.

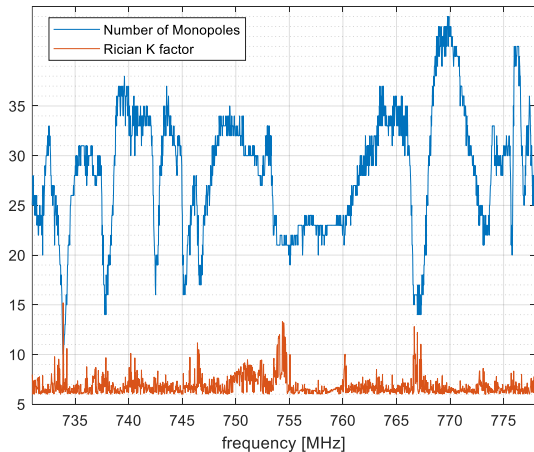


Fig.8. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 731-778 MHz.

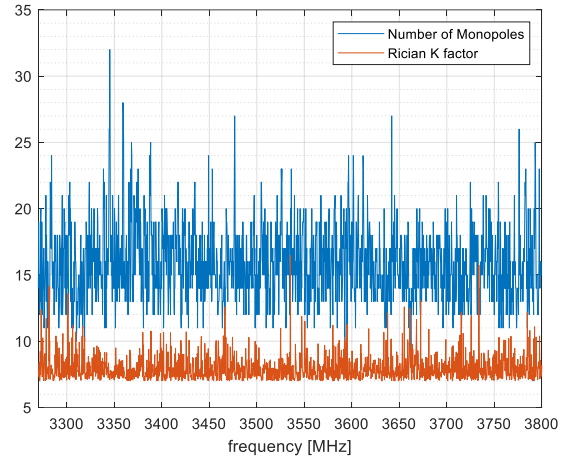


Fig.9. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 3270-3800 MHz.

B. Mechanical Stirred RC

Figs. 10 and 11 show the results obtained by applying the method to the S_{21} values, measured when the mechanical stirring action is implemented.

Two considerations should be done: the first one is that the method works successfully also with this kind of stirring technique.

The second one is that the MS has higher values of Rician K factor also considering all the 120 positions of the stirrer; for these reasons the final subset of S_{21} values selected by the algorithm has more element respect to the case of MMSS technique implemented.

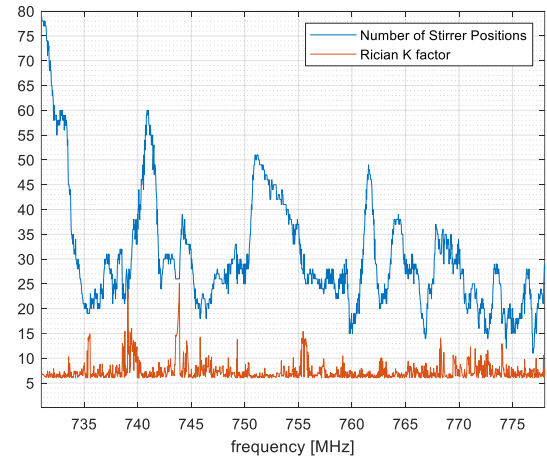


Fig.10. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 731-778 MHz

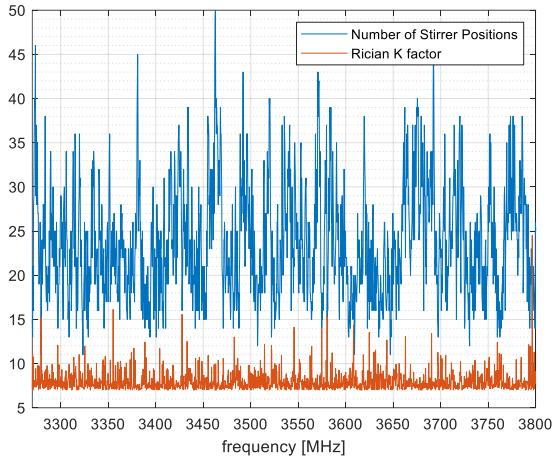


Fig.11. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 3270-3800 MHz

C. Oscillating Wall Stirred RC

The method was applied to the OWC RC. In this case the number of stirrer positions is 100 and it represents 100 different positions of the oscillating wall, that changes its geometry while it's moving.

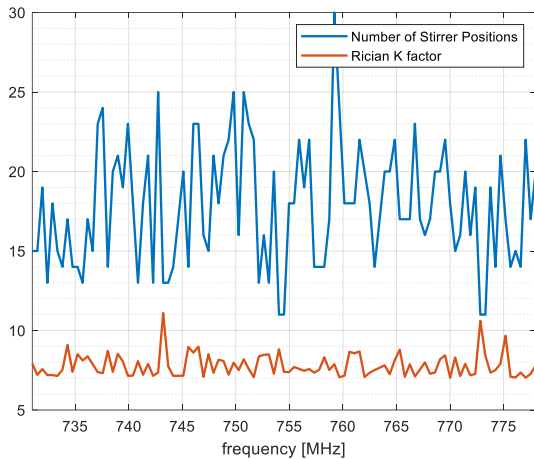


Fig.12. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 731-778 MHz

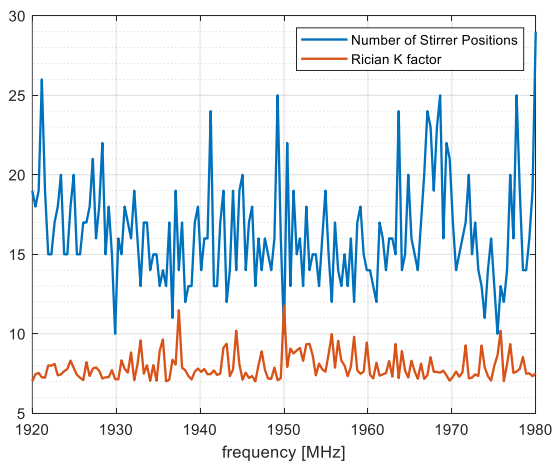


Fig.13. Rician K-factor and Number of electromagnetic field configurations selected by the algorithm in the frequency band 1920-1980 MHz

The target of a Rician K factor greater than 7 is reached both in the low (Fig. 12) and the mid (Fig. 13) frequency ranges. The number of the selected field configurations is comparable to the ones retrieved using the other considered stirring technique.

V. CONCLUSIONS

In this paper, it was experimentally validated the idea of tuning the Rician K factor of a reverberation chamber by selecting a proper subset of electromagnetic states.

The main advantage respect to the state of the art is that it is not necessary to add lossy elements, thus reducing the cost of the amplifier.

The main limitation is that the subset of electromagnetic states used to reach the goal varies with the frequency, thus affecting measurement times.

REFERENCES

- [1] J. A. Adebisola, A. A. Ariyo, O. A. Elisha, A. M. Olubunmi and O. O. Julius, "An Overview of 5G Technology," 2020 International Conference in Mathematics, Computer Engineering and Computer Science, pp.1-4, doi:10.1109/ICMCECS47690.2020.240853.
- [2] A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," in IEEE Access, vol. 3, pp. 1206-1232, 2015, doi: 10.1109/ACCESS.2015.2461602.
- [3] A. U. Gawas, "An Overview on Evolution of Mobile Wireless Communication Networks: 1G-6G," International Journal on Recent and Innovation Trends in Computing and Communication, 3(5), 2015.
- [4] R. Keating, M. Säily, J. Hulkkonen and J. Karjalainen, "Overview of Positioning in 5G New Radio," 2019 16th International Symposium on Wireless Communication Systems (ISWCS), 2019, pp. 320-324, doi: 10.1109/ISWCS.2019.8877160.
- [5] S. Medawar, P. Händel and P. Zetterberg, "Rician K-factor estimation and investigation of urban wireless measurements," 2012 IEEE International Conference on Wireless Information Technology and Systems (ICWITS), 2012, pp. 1-4, doi: 10.1109/ICWITS.2012.6417686.
- [6] A. Doukas and G. Kalivas, "Rician K factor estimation for wireless communication systems," International Conference on Wireless and Mobile Communications, Bucharest, Romania July 29-31, 2006.
- [7] A. Abdi, O. A. Dobre, R. Choudhry, Y. Bar-Ness, and W. Su, "Modulation classification in fading channels using antenna arrays," in Proc. IEEE MILCOM, 2004, pp. 211-277.
- [8] J. Medbo et al., "Radio propagation modeling for 5G mobile and wireless communications," in IEEE Communications Magazine, vol. 54, no. 6, pp. 144-151, June 2016, doi: 10.1109/MCOM.2016.7498102.
- [9] S. Zhu et al., "Probability Distribution of Rician K -Factor in Urban, Suburban and Rural Areas Using Real-World Captured Data," in IEEE Transactions on Antennas and Propagation, vol. 62, no. 7, pp. 3835-3839, July 2014, doi: 10.1109/TAP.2014.2318072.
- [10] C. L. Holloway, D. A. Hill, J. M. Ladbury, P. F. Wilson, G. Koepke and J. Coder, "On the Use of Reverberation Chambers to Simulate a Rician Radio Environment for the Testing of Wireless Devices," in IEEE Transactions on Antennas and Propagation, vol. 54, no. 11, pp. 3167-3177, Nov. 2006.
- [11] C. Lemoine, E. Amador and P. Besnier, "On the K -Factor Estimation for Rician Channel Simulated in Reverberation Chamber," in IEEE Transactions on Antennas and Propagation, vol. 59, no. 3, pp. 1003-1012, March 2011, doi: 10.1109/TAP.2010.2103003.
- [12] A. De Leo, P. Russo, and V. Mariani Primiani, "Emulation of the Rician K-Factor of 5G Propagation in a Source Stirred Reverberation Chamber," Electronics, vol. 12, no. 1, p. 58, Dec. 2022, doi: 10.3390/electronics12010058.
- [13] A. De Leo, V. M. Primiani, P. Russo and G. Cerri, "Low-Frequency Theoretical Analysis of a Source-Stirred Reverberation Chamber," IEEE Transaction on Electromagnetic Compatibility vol. 59, no. 2, pp. 315-324, April 2017. DOI: 10.1109/TEMC.2016.2613402

- [14] A. De Leo, V. M. Primiani, P. Russo and G. Cerri, "Numerical analysis of a reverberation chamber: Comparison between mechanical and source stirring techniques," 2017 International Symposium on Electromagnetic Compatibility - EMC EUROPE, Angers, 2017, pp. 1-6, doi: 10.1109/EMCEurope.2017.8094648.
- [15] A. De Leo, G. Cerri, P. Russo and V. Mariani Primiani, "Experimental Comparison Between Source Stirring and Mechanical Stirring in a Reverberation Chamber by Analyzing the Antenna Transmission Coefficient," 2018 International Symposium on Electromagnetic Compatibility (EMC EUROPE), Amsterdam, 2018, pp. 677-682, doi: 10.1109/EMCEurope.2018.8485091
- [16] D. Barakos and R. Serra, "Performance characterization of the oscillating wall stirrer," in Proc. IEEE Int. Symp. Electromagn. Compat., Angers, France, Sep. 4-7, 2017, pp. 1-4.
- [17] R. Serra and D. Barakos, "A novel hybrid source-tuner stirring allows for an extended working volume in RCs," in Proc. IEEE Int. Symp. Electromagn. Compat., Amsterdam, Netherlands, Aug. 27-30, 2018, pp. 699-703.
- [18] Online available: <https://cms.law/en/int/expert-guides/cms-expert-guide-to-5g-regulation-and-law/italy>, accessed on the 12th January 2023.
- [19] Online available: <https://halberdbastion.com/technology/cellular/5g-nr/5g-frequency-bands>, accessed on the 12th January 2023.