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26 June 2026

Rician K Factor Fluctuation in Reverberation Chambers

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***Abstract*— Reverberation chambers play a fundamental role in evaluating the efficacy of wireless communication systems by providing controlled environments for testing. One crucial aspect of this assessment is the manipulation of the Rician K factor within these chambers. The inherent challenge lies in the typically low values of the Rician K factor, necessitating intentional adjustments to replicate real-world communication scenarios accurately. This paper aims to present the statistical analysis of the Rician K factor, focusing on the various measures undertaken to modulate this parameter. The experimentation involves a comprehensive examination of actions taken to tune the Rician K factor. One of the key strategies involves the strategic insertion of lossy elements within the reverberation chamber. These elements introduce intentional signal attenuation, impacting the Rician K factor and contributing to a more realistic simulation of wireless communication conditions. The paper delves into the intricacies of selecting and placing these lossy elements to achieve the desired level of signal degradation and, consequently, an appropriate Rician K factor. Furthermore, the investigation considers the positioning of these lossy elements within the reverberation chamber. The spatial distribution and arrangement of these elements can significantly influence the electromagnetic field characteristics, affecting the Rician K factor. In addition to the insertion and placement of lossy elements, the orientation of the receiver within the chamber emerges as another factor under analysis. The paper explores how variations in receiver orientation impact the statistics of the Rician K factor.**

Keywords: mechanical stirring; reverberation chamber; Rician K factor; statistical analysis.

I. INTRODUCTION

Rician K factor is one of the indicators used to evaluate the statistics of a propagation environment for wireless communications systems [1]. This parameter indicates the dominance of the direct signal component relative to the scattered one, providing crucial insights into the wireless communication channel.

Generally, as the parameter K rises, the probability of encountering substantial signal fade diminishes. Conversely, a decrease in K results in a weakening of the primary signal path. Upon reaching 0, the received signal distribution shifts from Rician to Rayleigh. The K factor, representing the relative power of the dominant component, serves as a crucial metric for evaluating the quality of communication links. Therefore, precise estimation of K is of practical importance in various wireless scenarios, including channel characterization, adaptive modulation, and localization applications [2].

In the intricate realm of 5G communication systems, the characterization of propagation environments is encapsulated by the Rician K-factor (K), with values typically falling within the range of several units, lower for urban and indoor scenarios, higher for suburban and rural environments [3] – [7].

In contraposition, when considering Reverberation Chambers (RCs) lower K-values are observed with respect to propagation environments [8] – [9]. This deviation arises from the deliberate design choice wherein the stirred electromagnetic field component within these chambers needs to surpass the influence of the unstirred component.

The specific multipath environment inside a RC has been proposed for emulating a rician environment typical of communication systems, providing the increase of its K-factor [8]. The objective of testing inside a RC is to have a well controllable environment with pre-determined K-factor. Different technique has been proposed for controlling and increasing the K-factor of a reverberation chamber. The traditional approach involves the insertion of lossy elements. In this way the level of scattered electromagnetic field within the chamber is reduced, thereby increasing the K-factor. However, this maneuver comes with a trade-off. While it effectively heightens the K-factor, it simultaneously leads to a reduction in the quality factor of the chamber.

The quality factor is a measure of the efficiency of signal storage in a resonant system, and in the context of RCs, a lower quality factor indicates a higher level of signal dissipation. As lossy elements are integrated to manipulate the K-factor, the overall quality factor of the chamber diminishes. This decline in quality factor implies that the reverberation time decreases, and the chamber becomes less effective in sustaining electromagnetic energy over time.

Consequently, to maintain the desired electromagnetic field intensity within the RC despite the inclusion of lossy elements, compensatory measures are required. This often entails employing additional amplification to achieve and sustain the same level of electromagnetic field intensity within the chamber. The intricate balance between enhancing the K-factor, managing the quality factor, and compensating for signal losses underscores the delicate engineering considerations inherent in optimizing Reverberation Chambers for specific testing and experimentation scenarios within the realm of wireless communication and electromagnetic field studies.

An alternative technique for increasing the K-factor inside a RC was presented in [10]. The method proposed offers the possibility of increasing the K-factor without increases the losses into the chamber, leading to preserve the high signal level typical of RC. The algorithm proposed is based on the selection of electromagnetic field configurations realizable inside a reverberation chamber. The versatility of the algorithm is particularly notable, as asserted in [11], suggesting that its application is theoretically extendable to a wide typology of RCs, provided that the stir states are repeatable.

The apparent limit of this algorithm is that the obtained K-factor is influenced by the starting stir state and by the choice done in the algorithm (i.e. the algorithm chooses the configurations with the majority of final stir states). Changing the starting number of initial stir states or the algorithm constraints, the procedure can lead to a K-factor that lies within an interval around the desired target. However, this limitation is only apparent compared to the traditional technique of mimicking a K-factor within a reverberation chamber, in fact also in this case the K-factor is not unique inside the chamber, and it can be influenced by different parameters.

This paper has the objective of exploring the parameters that can influences the tuning of the Rician K factor within reverberation chambers when the traditional approach is used. In particular three aspects are considered. The first focal point centers on the strategic insertion of lossy elements within the chamber to deliberately augment the Rician K factor. This deliberate introduction of signal attenuation is crucial in emulating real-world communication scenarios where signal reflections, obstacles, and other environmental factors influence signal strength. The paper meticulously investigates the impact of these lossy elements, examining how their incorporation dynamically influences the Rician K factor and, consequently, the accuracy of the testing environment.

A second facet of the study delves into the spatial dynamics associated with the positioning of these lossy elements. The placement of these elements within the reverberation chamber affects the Rician K factor values and therefor its statistics.

Furthermore, the third aspect of the study focuses on the orientation of the receiver within the chamber and its consequential impact on the fluctuation of the Rician K factor. The orientation of the receiver is a critical variable, as it can significantly influence signal reception and, consequently, the Rician K factor. By systematically varying the receiver orientation, the paper seeks to measure the corresponding variability of the Rician K factor on this experimental setting.

II. EXPERIMENTAL SETUP

The RC used in all the sets of measurements in a quasi-cubic RC, having dimensions 1.0 m times 0.9 m times 0.8 m, made by galvanized steel, and stirred by a mechanical action achieved rotating a Z shaped metallic stirrer (Figure 1). More details on the chamber and its experimental characterization can be found in [12].

Fig.1. The Reverberation Chamber and its mechanical stirrer.

We chose to investigate one of the 5G frequency bands available in Italy, from 3.27 to 3.80 GHz, where the RC is well overmoded.

The transmitting antenna is the disc cone antenna depicted in Figure 2; it is a broadband antenna able to cover the whole investigated frequency range.

Fig.2 The disc cone transmitting antenna.

The receiving antenna (Figure 3) is a double C shaped slot antenna having a ground plane; in this way we emulated the radiating behavior of a cellular phone that emits only in a half space to reduce the power radiated into the head of the user, when placed close to the ear in the classical calling position.

This antenna is well matches in the lower part of the considered frequency range and bad matched in the higher part. This characteristic is interesting to see the possible effect of the antenna mismatching of the Rician K factor.

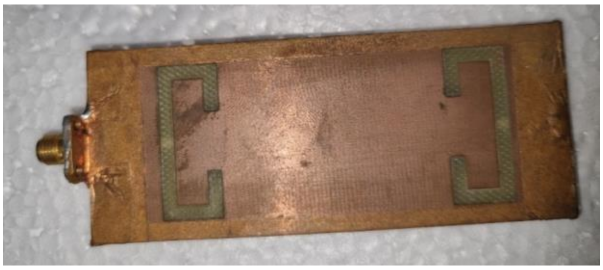


Fig 3. The double C receiving antenna.

Both antennas are homemade and their reflection coefficients in the considered frequency band are reported in Figure 4.

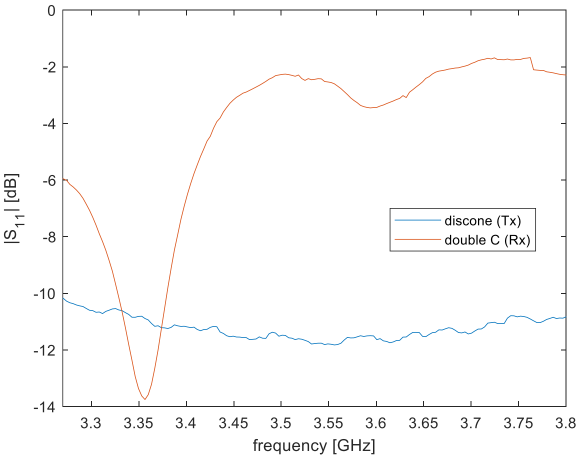


Fig.4. Measured reflection coefficients for the disc cone and the double C antenna.

III. RESULTS

In this section the statistical analysis related to three different sets of measurements is reported. In the first set, the fluctuations of the Rician K factor were analyzed increasing the number of lossy elements inserted into the chamber. In the second set, we fixed the number of lossy elements, and their positions were varied with the constraint to keep the minimum distance between them greater than half a wavelength, according to [13] [14]. In the last set, we varied the orientation of the receiver, simulating the realistic scenario of user holding cellular phone in any relative direction respect to the radio base station.

In all the considered scenarios, the Rician K factor was computed according to equation (1).

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

where S_{21} is the transmission coefficient between the transmitting and the receiving antennas measured by the Vectorial Network Analyzer (VNA), and <·> means the average over all the electromagnetic realization of the chamber (100 stirrer positions, rotation angular step 3.6°).

As an example of K-factor within a RC, Figure 5 shows the variation of the Rician K factor with frequency inside our chamber without the presence of lossy element inserted.

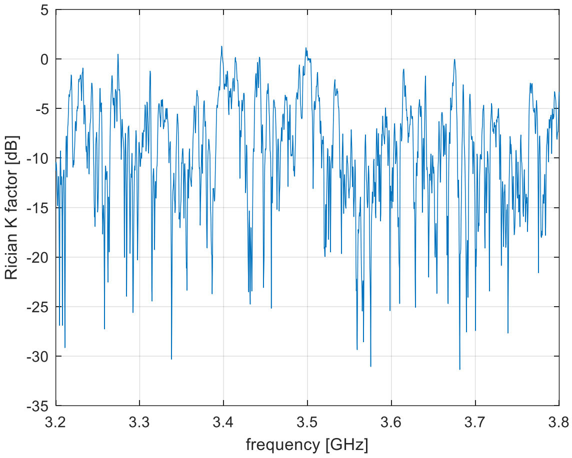


Fig.5. Measured Rician K factor for the lossless configuration of the RC.

It is possible to define the standard deviation of K values respect to its frequency variation, according to equation (2)

$$\sigma(K)_{dB} = 10\,log_{10}((\mu(K) + \sigma(K))/\mu(K)) \qquad (2)$$

Where $\mu(K)$ represents the mean value, averaged on the investigated frequency band, of the Rician K factor, and $\sigma(K)$ is its standard deviation. For the scenario related to Figure 5, $\sigma(K)_{dB} = 3.15\ dB$.

A. Rician K factor fluctations varying the number of lossy elements

In the first set of measurements, the number of lossy elements inserted into the RC was increased from 0 to 32. The single lossy element is made of one pyramid element, cut from a 30-element pyramidal absorber ECCOSORB VHP-8-NRL.

Figure 6 shows the values of $\mu(K)$ and $\sigma(K)_{dB}$ for different number of lossy elements. It can be observed that, as expected, the mean value of the Rician K factor increases, while the value of the standard deviation is almost constant, assuming values close to 3 dB.

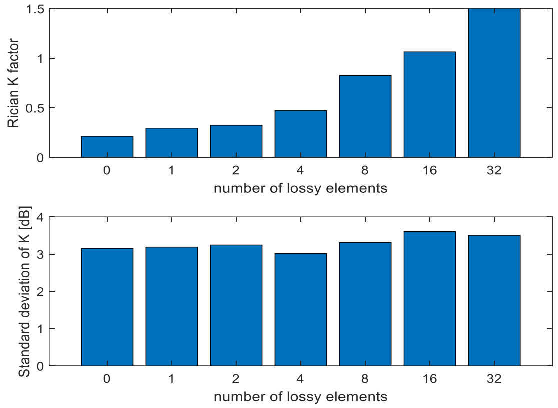


Fig.6. The Rician K factor and its standard deviation behavior while adding lossy elements into the chamber.

B. *Rician K factor fluctations varying the diplacement of 8 lossy elements*

In the second set of measurements, the number of lossy elements was constant (8 lossy pyramids), but their placement inside the RC was changed, keeping their minimum distance greater than half a wavelength. In this case (Figure 7) it was observed a small variability of the mean value of the Rician K factor and of its standard deviation.

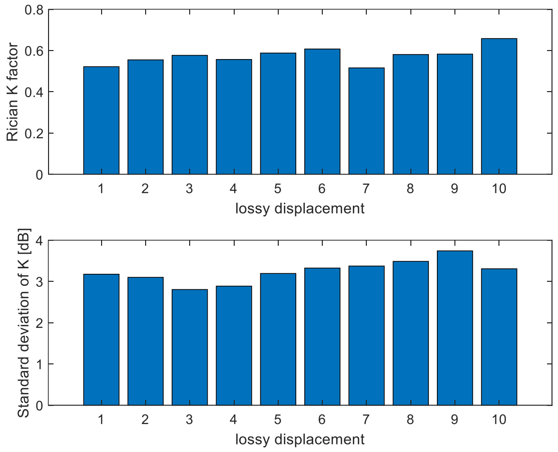


Fig.7. The Rician K factor and its standard deviation behavior changing the position of the 8 lossy elements inserted into the chamber.

C. *Rician K factor fluctations varying the orientation of the receiver*

In the third set of measurements, it was investigated the effect of the orientation of the receiver on the Rician K factor. In the real life, the user might turn the mobile device in many positions, ranging from a horizontal to a vertical orientation. Moreover, the relative position of the radio base is unpredictable and the effect of scattering elements, as the buildings, change the polarization of the electromagnetic wave transmitted by the source. Figure 8 shows the 12 angular positions of the device that were considered in this subsection. Moreover, two orientations of the receiver were considered (horizontal and vertical) and two loading states of the chamber (unloaded and with 8 lossy elements inserted into the RC). We have 4 scenarios with 12 rotation angles (30° angle step) for a total of 48 sets of measurements.

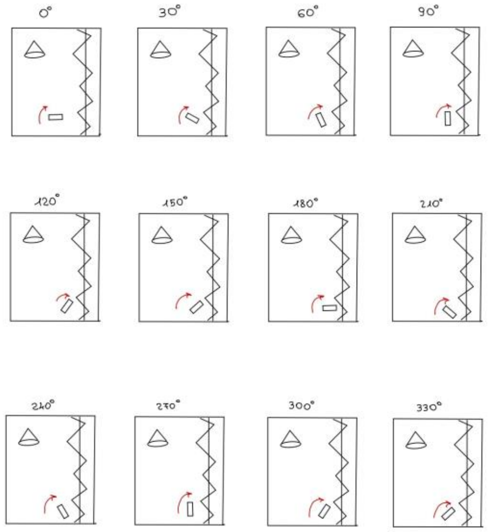
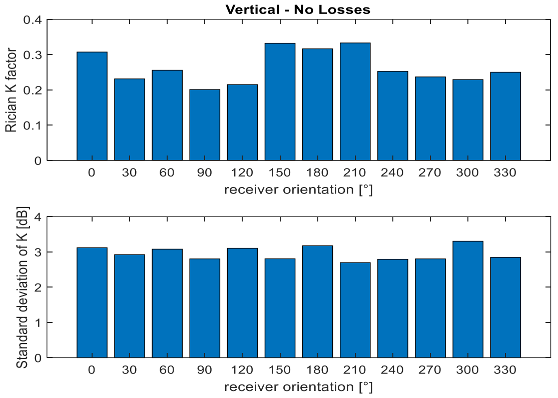
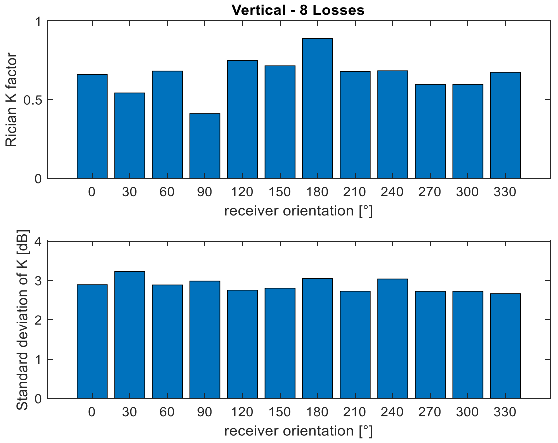


Fig.8. The 12 considered rotation angles of the receiving antenna, adopted in both vertical and horizontal orientations.

In this case (Figure 8) it was observed that in all the 4 considered scenarios, the standard deviation of the Rician K factor assumes values close to 3 dB.





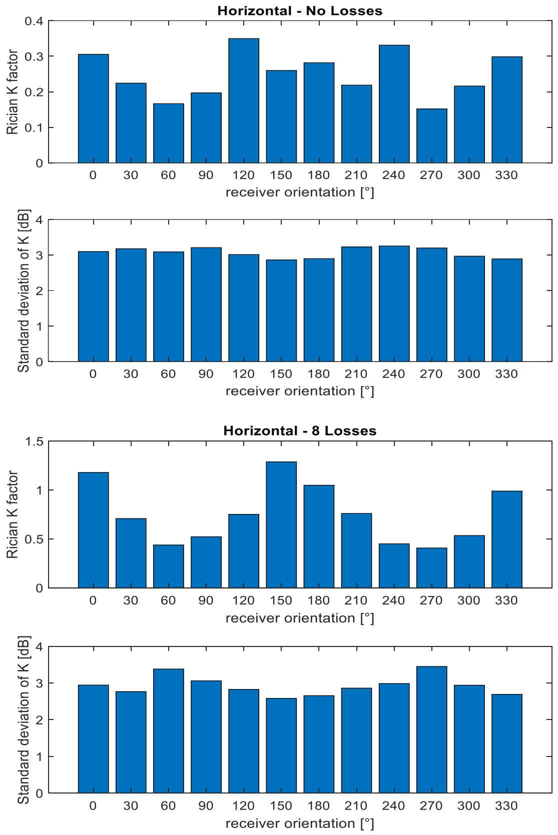
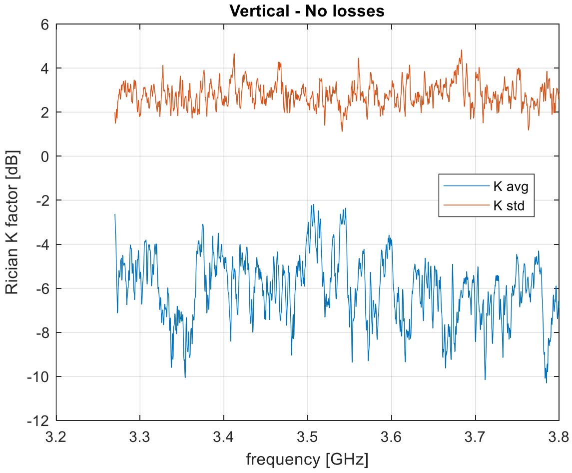
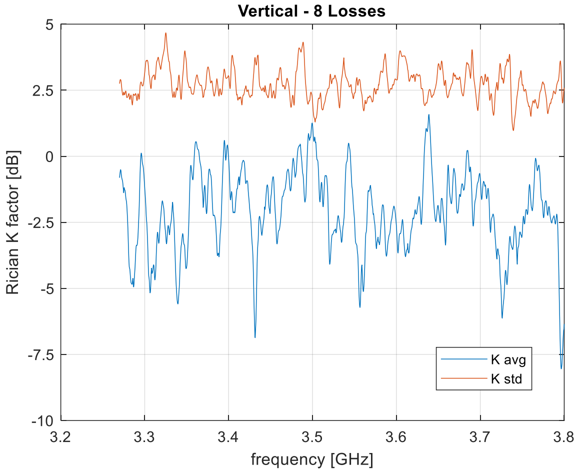
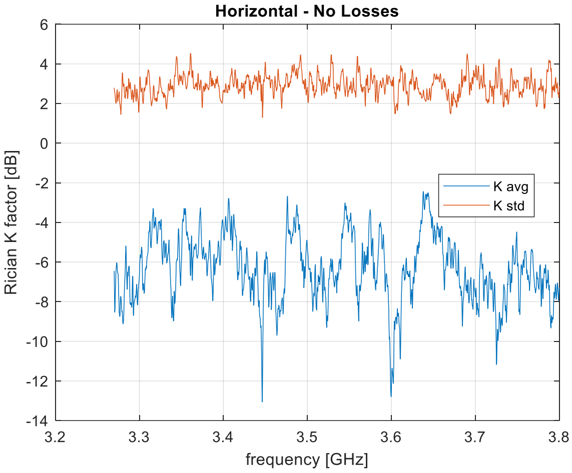


Fig.9. The Rician K factor and its standard deviation behavior changing the orientation of the receiver, considering horizontal and vertical position and lossless and lossy scenarios (8 lossy elements).

For this third case study a further frequency investigation has been performed. Figure 10 shows in all the considered scenarios the fluctuation with the frequency of the Rician K factor. In this case, the K-factor, computed according to equation (1), is reported as averaged value over the 12 angular orientations. The standard deviation is computed over the 12 angular rotations too and reported for each frequency point in the investigated range. It can be noted that the standard deviation assumes values between 2 and 4 dB in all the considered scenarios. Observing the frequency dependent waveform of the K-factor, it can be noticed that there are no significant differences between the frequency band where the receiving antenna is well matched (3.2 to 3.4 GHz) and the one where the antenna is mismatched.







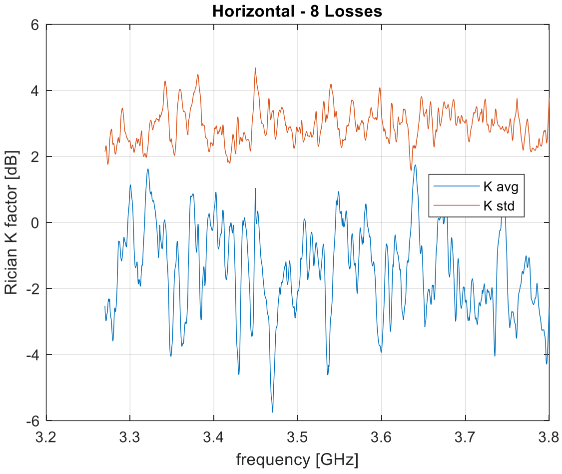


Fig.10. Rician K factor and its standard deviation varying the orientation of the receiver. Vertical and horizontal positions in lossless and lossy scenarios are considered.

IV. CONCLUSIONS

This paper undertakes an investigation into the impact of loss insertion, the placement of lossy elements, and the orientation of the receiver on the statistical characteristics of the Rician K factor inside a RC. The analysis was applied to a mechanically stirred RC. The possibility of having a controllable environment is limited by the influence of these parameters. In particular, one of the less investigated parameters is the orientation of the receiver inside the RC.

The results of our analysis indicate that a discernible fluctuation of K-factor within the range of 2 to 4 dB, is observed.

Future work will extend the analysis using different reverberation chambers, varying their dimensions, their stirring actions, and the considered frequency ranges.

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