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The Effect of Zigzag Boundaries on the Reverberation Chamber Performance

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ABSTRACT The stirrer design is important in a reverberation chamber measurement system. Previous study shows that the rotating radius of the stirrer plays a key role for the stirrer performance. However, to identify the contribution from the structure, optimizing the stirrer structure while keeping the stirring volume unchanged is necessary. In this paper, when the stirring volume is kept invariant, we show that the detailed structure of stirrers can be optimized to improve the performance but the effect is not significant. A comparative study is given to confirm the effect of zigzag boundaries on the stirrers. Both simulations and measurements confirm the performance improvement, key performance indicators such as field uniformity and correlated angles are simulated and measured.

INDEX TERMS Field uniformity, reverberation chamber, stirrer design.

I. INTRODUCTION

Reverberation chamber (RC) system has attracted many research attentions in the area of electromagnetic compatibility (EMC) [1] and over-the-air (OTA) testing [2] in recent years. Typical measurements such as radiated susceptibility [1], total radiated power [3] shielding effectiveness [1], antenna efficiency [4]–[6], total isotropic sensitivity [7], [8], throughput [9], [10], diversity gain [11]–[13] and channel capacity [11]–[13] can be measured in an RC system. Depends on the applications of an RC, the design of an RC is a systematic project. How to achieve an optimized RC system is a common problem for all RC designers worldwide.

For a given material, the performance of an RC typically depends on two aspects: the dimensions of the cavity and design of stirrers (including the stirring mechanism [14]). The dimensions of an RC play a key role for the RC performance, because the RC works in the overmoded region, when the electrical dimensions of a cavity are not large enough, it may not be possible to support enough modes at low frequencies. Once the dimensions of a cavity are given, the design of stirrers becomes the key problem. The stirrer design and optimization has been studied for years [15]–[29]. It is believed that by increasing the current length at the edge of the stirrers, the stirrers can interact with waves at lower frequencies more effectively [29]–[32]. This methodology has been widely used in antenna designs to reduce the physical size or lowering the working frequency of antennas. Some important empirical guidelines have been summarized [1]:

a) The stirrers have one dimension that is at least a quarter wavelengths at the lowest usable frequency (LUF);
b) The stirrers should have one dimension at least three-quarters of the smallest chamber dimensions;
c) The stirrers should be shaped asymmetrically to avoid repetitive field pattern in an RC.

Existing research have confirmed that the rotating radius (stirring volume) plays a key role for the stirrer performance which is intuitive, as a big stirring volume means a good stirrer. However, a big stirring volume also means a smaller working volume, thus there is a tradeoff between the maximum of working volume and the minimum of working frequency [33]. For two different stirrers with the same stirring volume, how the detailed structures affect the stirring performance need to be confirmed. When two stirrers have different boundary shapes, it could be difficult to identify the contribution of the improvement from the stirring volume or from the structure details (or from both). This paper is aimed to solve this problem.

In this paper, we present a comparative study on the stirrer shape effect while keeping the stirring volume unchanged.

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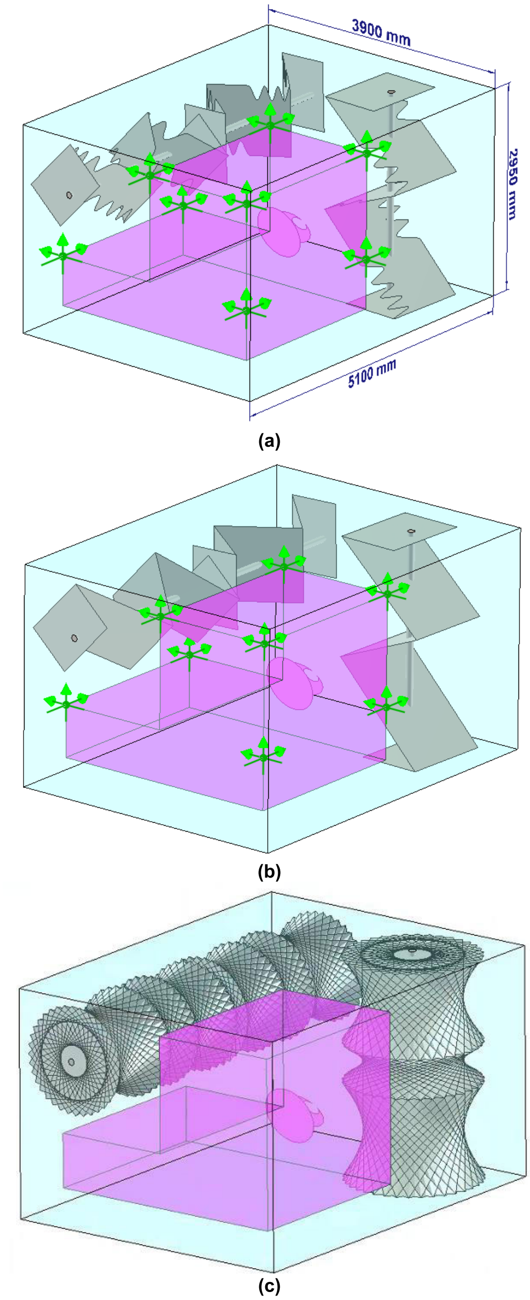


FIGURE 1. Simulated model (a) with and (b) without zigzag boundaries, (c) the stirring volume, the stirring volume of the horizontal and the vertical stirrers are 4.93 m^3 and 4.60 m^3 respectively.

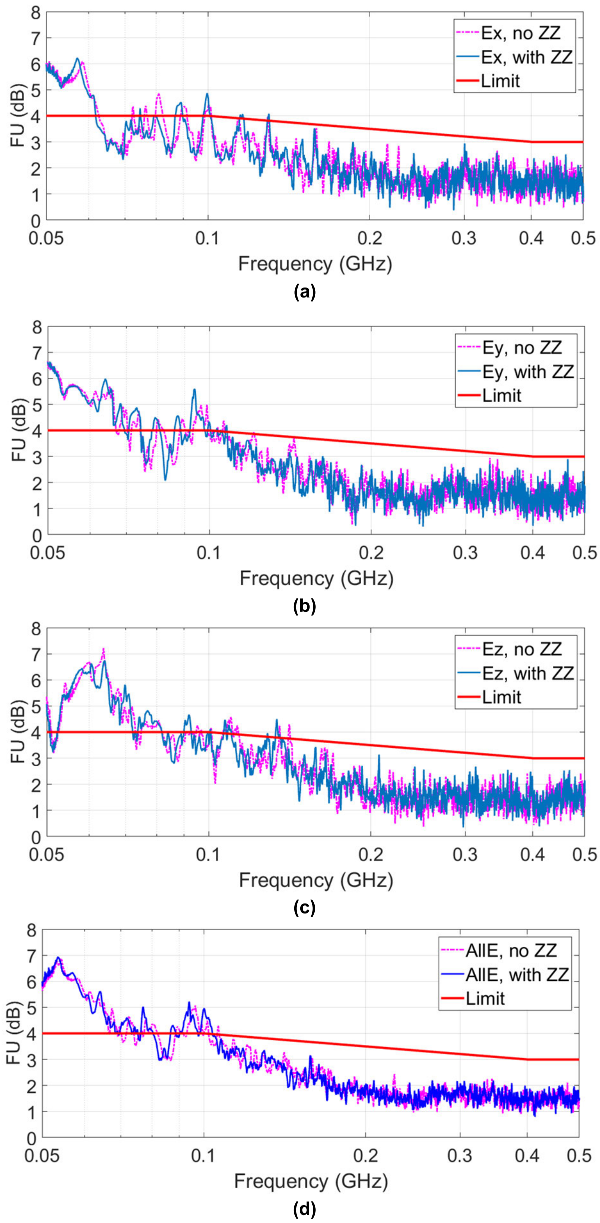


FIGURE 2. Simulated FU of different E-field components, 'no ZZ' means the stirrer boundaries are flat while 'with ZZ' means the stirrer boundaries are cut with zigzags.

Aluminum foils are used to cover the zigzag boundaries to create a comparative scenario. In Section II, we present the RC design and the simulation results. In Section III, measurements are performed and the results are validated, further investigations are given in Section IV and conclusions are finally given in Section V.

II. RC DESIGN AND SIMULATION RESULTS

There are many metrics to characterize the RC performance (e.g. enhanced backscatter coefficient, stirring ratio, anisotropy, correlation matrix, *etc*.). In this paper, the metrics defined in the IEC 61000-4-21 standard [1] are mainly used. The maximum E-field is used to calculate the field uniformity (FU), while for OTA applications the mean value of the received power is used. The inner dimensions of the RC are 3.9 m × 5.1 m × 2.95 m, the rotating radius of the horizontal stirrer and the vertical stirrer are 0.7 m and 0.88 m respectively. Eight field probes are located at the testing volume with are at least $\lambda/4$ from the boundaries or stirrers [1], λ is estimated as 1.5 m which is the wavelength at 200 MHz. The simulated models with and without zigzag boundaries are illustrated in Fig. 1(a) and (b). Note that only one side of stirrers has zigzag boundaries and the opposite side is kept unchanged, thus the zigzag boundaries do not affect the stirring volume (shown in Fig. 1(c)).

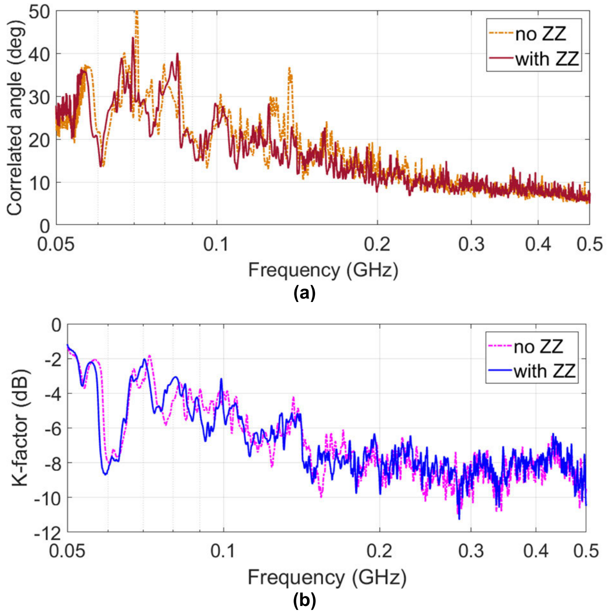


FIGURE 3. Simulated (a) averaged correlated angles and (b) K-factors.

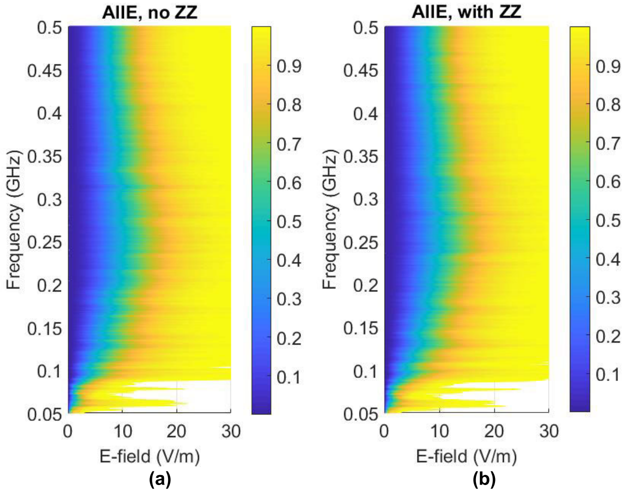


FIGURE 4. Simulated ECDF plots for all E-field components, (a) no zigzag boundaries, (b) with zigzag boundaries.

TABLE 1. Measurement configurations.

Measurement	Antenna position no.	Frequency point no.	Stirrer position no.
FU	24	10,001	90
Q factor	1	100,001	60
Correlated angle	1	10,001	360

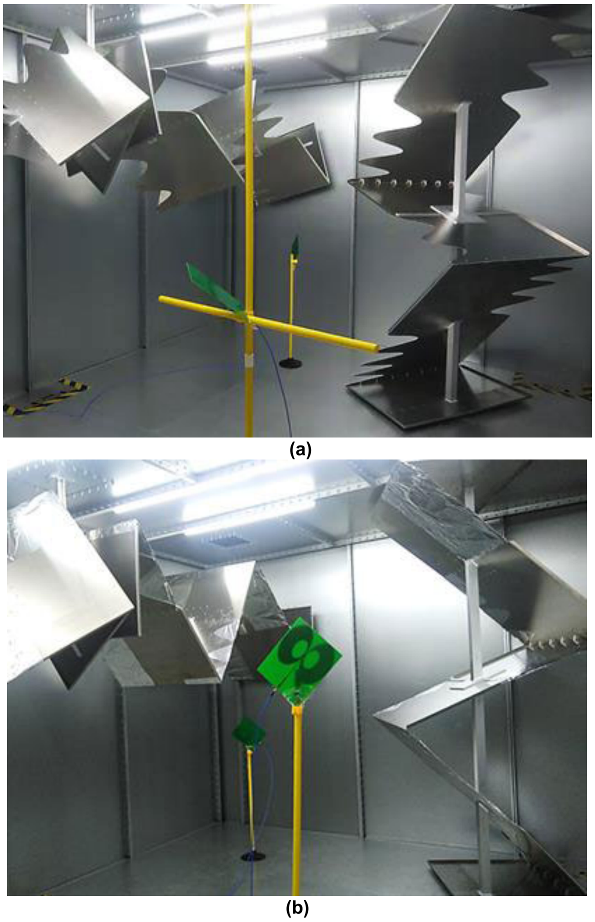


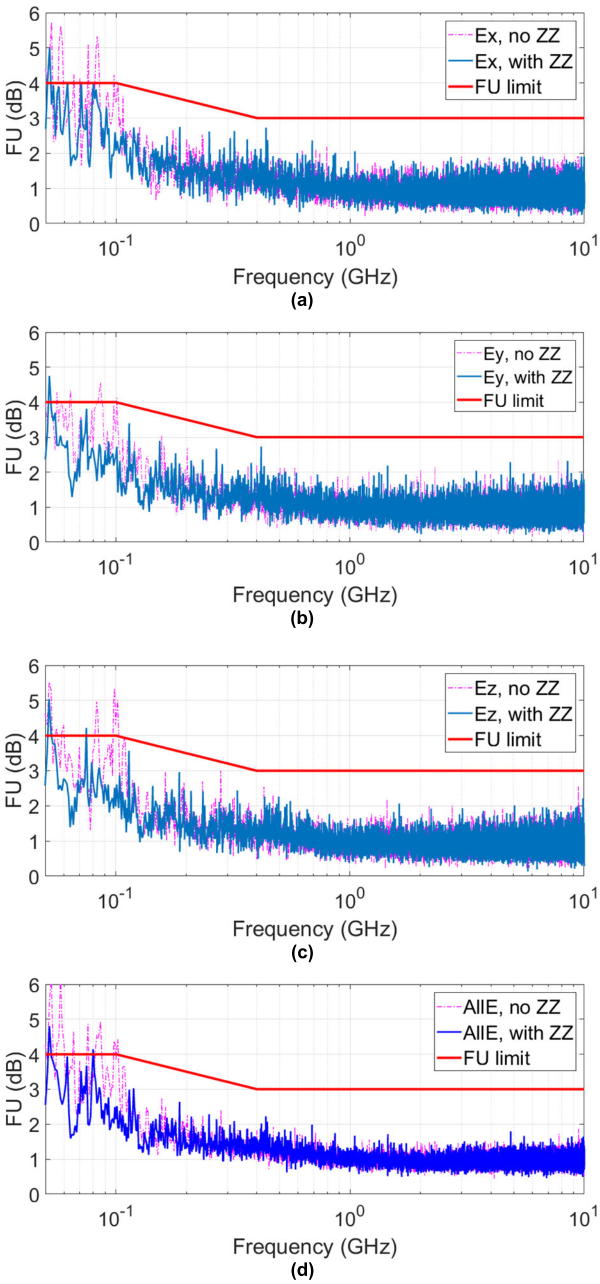
FIGURE 5. Measurement scenarios in the RC at Nanjing University of Aeronautics and Astronautics, (a) zigzag boundaries and (b) no zigzag boundaries.

In the simulation, the two stirrers are rotated synchronously with 2°/step, 180 stirrer positions are simulated using the Finite Integral Time Domain (FITD) method in CST software. From the measured Q factor, the material property is inverted and a conservative volumetric loss is used with $\varepsilon_r = 1 + \beta_0/(\alpha_0 + j\omega)$, where $\beta_0 = 4.33 \times 10^6$ Hz and $\alpha_0 = 5.53 \times 10^5$ Hz. All the E-fields at the corner of the testing volume are recorded and the FU is calculated according to IEC 61000-4-21 [1]. The total mesh number is about 7 million, and the simulation time of 180 stirrer positions is about 24 hours with GPU (Graphics Processing Unit) acceleration.

The simulated FU of the maximum values of E_x, E_y and E_z are illustrated in Fig. 2(a)-(c) and the FU with all polarizations are given in Fig. 2(d). Note that the FU curves with zigzag boundaries are shifted toward lower frequencies, but the effect is not significant (a few MHz).

The correlated angles [1] and K-factors [3] from 24 probe scenarios (8 positions × 3 polarizations) are averaged and are illustrated in Fig. 3(a) and (b), similar effects are also observed, the curves with zigzag boundaries are shifted to lower frequencies with a few MHz. At high frequencies (above 150 MHz), the differences are not significant, which means the stirrer performance with and without zigzags is already good enough.

We also checked the empirical cumulative distribution function (ECDF) plots in Fig. 4 for the E-fields with and without zigzag boundaries, which show no significant difference. We changed the polarization and the position of the transmit antenna and repeat the simulations, the conclusions still hold for the boundaries with and without zigzags.



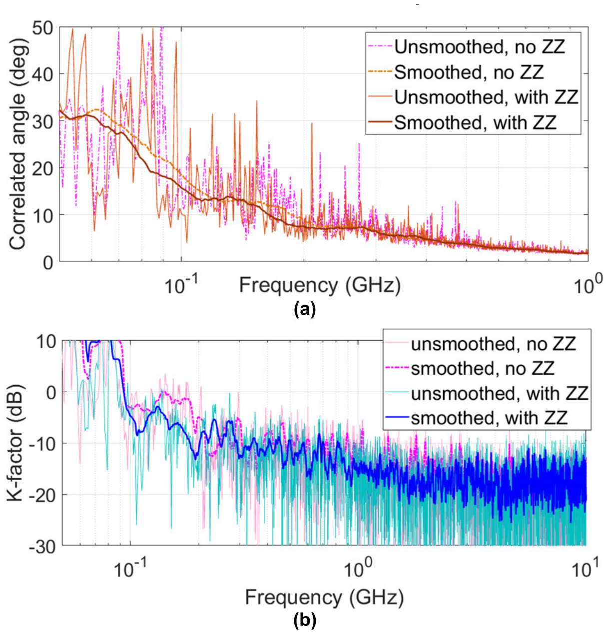
(a)

(b)

(c)

(d)

FIGURE 6. Measured FU of different E-field components.



(a)

(b)

FIGURE 7. Measured (a) averaged correlated angles and (b) *K*-factors.

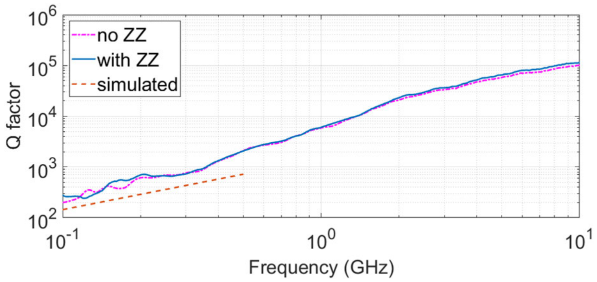


FIGURE 8. Measurement scenarios with (a) zigzag boundaries and (b) no zigzag boundaries.

III. MEASUREMENTS

After the RC is built, measurements are performed with and without zigzag boundaries. In the no zigzag scenario, we use aluminum foils to cover the zigzag edges and repeat the measurements. The measurement scenarios are shown in Fig. 5(a) and (b). Measurement settings are detailed in Table 1. The time domain technique [5], is used to extract the Q factors at different frequencies.

The measurement results are presented in Fig. 6-Fig. 7. Note that the FU is improved at low frequencies around 100 MHz. The correlated angles are reduced slight (a few degrees) and the K-factors are also improved. The measured Q factors are given in Fig. 8 which confirms that the Q factors are not affected too much when aluminum foils are added. It can be seen that the Q factor is slightly reduced at high frequencies because of the aluminum foils. The Q factors used in the simulation are also given, which are lower than the measured values. This is because we need to use conservative values in the design process; if the simulated Q factor is higher than the measured value, the RC performance could be overestimated.

IV. FURTHER INVESTIGATIONS

In the comparative study with and without zigzags, we kept other factors invariant and only change the boundary shapes. The results show that the zigzag boundaries can improve the RC performance. Typical figures of merit are shifted to lower frequencies. We also note that the improvement is not significant (a few MHz) in both simulations and measurements. There could be due to two reasons: 1) the performance of the original stirrers are already good enough which leads the effect of the extra zigzags not significant; 2) the contribution of the zigzag boundaries is indeed not significant.

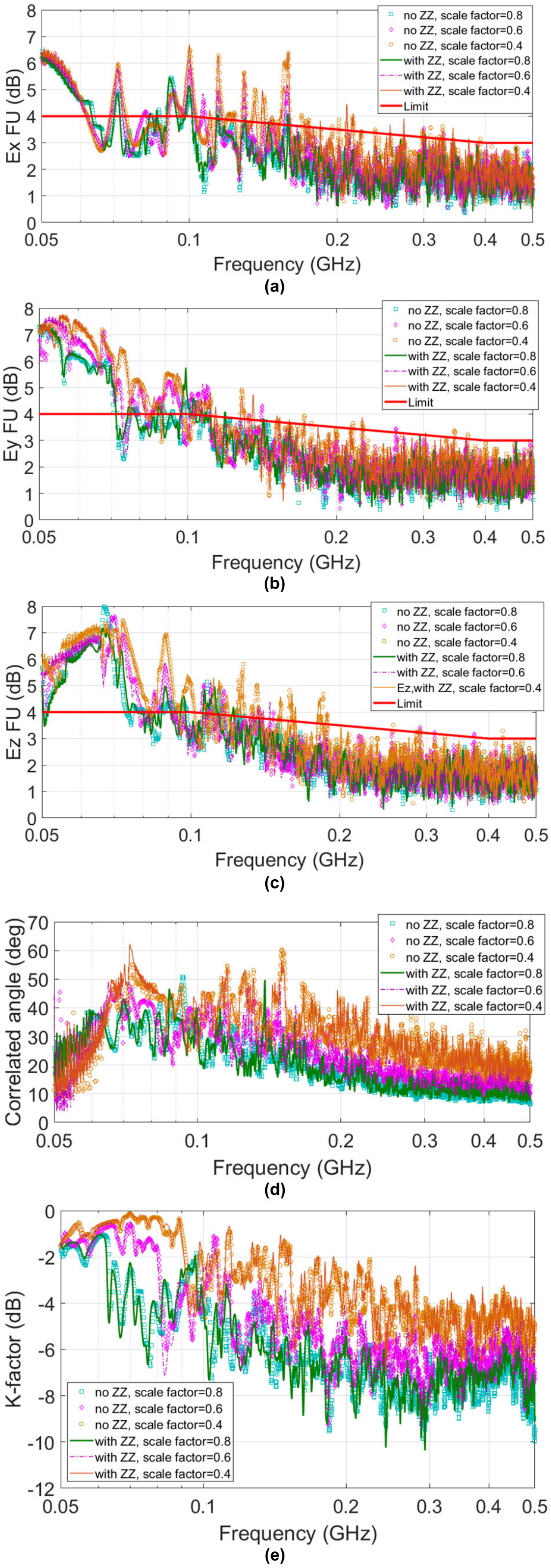


FIGURE 9. **Simulated results with and without zigzag boundaries with different scale factors, (a) simulated FU of Ex, (b) simulated FU of Ey, (c) simulated FU of Ez, (c) simulated correlated angles, (d) simulated K-factors.**

To investigate this, we scale the rotating radius (with a scale factor) of two stirrers and compare the simulated results with and without zigzags. In this way, the stirring volumes are reduced, and the working volume is not changed. The results are illustrated in Fig. 9. We can find there are slightly frequency shifts for curves with scale factor $= 0.8$, and this frequency shift is smaller than the original model (scale factor $= 1$). The differences are not significant for scale factors smaller than 0.8.

V. CONCLUSION

We have performed a comparative study on the effect of zigzag boundaries on the RC performance. Results from simulations and measurements show that the zigzag boundaries can improve the RC performance when the stirrers are large, and this improvement is not significant (a few MHz). The radius of the stirrers plays the key role and dominates the stirrer performance.

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