Author post-print

Changes in a Printed Circuit Board's Absorption Cross Section Due to Proximity to Walls in a Reverberant Environment

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Abstract—**Knowledge of the absorption cross section (ACS) of a printed circuit board (PCB) is essential when defining an enclosure's shielding effectiveness as it will determine how a PCB affects the internal electromagnetic (EM) field inside the enclosure. In this paper we show how the ACS changes when a PCB is in the vicinity of the enclosure walls by making measurements in a small reverberation chamber. We find that when the PCB is perpendicular to the chamber wall different measurement positions have little effect on the ACS, even when the PCB is positioned close to the wall. However, placing the PCB parallel to the chamber wall did show some differences in ACS. This information could be useful when considering situations where PCBS are stacked together or close to enclosure walls when in a reverberant environment.**

Keywords—enclosure shielding, absorption cross section, reverberation chamber, printed circuit board

I. INTRODUCTION

The Shielding Effectiveness (SE) of an enclosure is a measure of how well it reduces the Electromagnetic (EM) field inside it compared to that incident upon it. It is generally specified for an empty enclosure and one method of defining it is the ratio of incident power density on the enclosure to the power density inside the enclosure. In reality the enclosure will contain contents such as Printed Circuit Boards (PCBs) and the SE will be affected by the energy absorbed by these contents [1]. Knowledge of the Absorption Cross Section (ACS) of an object allows the energy absorbed by it to be quantified.

Initial ACS measurements of individual PCBs in a reverberation chamber have been reported in [2] using the method described by Carlberg in [3]. In this paper we examine the effect on the ACS when a PCB is positioned in different locations in a reverberation chamber. These locations included some with the PCBs close to the chamber wall, in both parallel and perpendicular orientations. Determining how the ACS changes in different positions in a reverberation chamber can be applied to investigating how it changes in a shielded enclosure. An increased or decreased ACS will change the EM field internal to the enclosure thus also changing its shielding effectiveness.

Section II of this paper outlines the theory and calculation of ACS. In Section III the PCBs used for the measurements are described with the measurement setup and methodology detailed in Section IV.. Section V discusses the measurement results and Section VI concludes the paper.

II. ABSORPTION CROSS SECTION

As measured in a reverberation chamber the average ACS of an object is defined as the ratio of the average power absorbed to the average power density of the incident field and is given by [3] as:

$$< \sigma_\mathrm{a} > = \frac{\lambda^2}{8\pi}\left(\frac{1}{G_\mathrm{wo}} - \frac{1}{G_\mathrm{no}}\right),$$ (1)

where $<\sigma_\mathrm{a}>$ is average ACS, λ is the wavelength, G_wo is the mean net power transfer function with the object in the reverberation chamber and G_no is the mean net power transfer function without the object. The angle brackets $<\ldots>$ indicate averaging over stirrer positions and frequencies. G_wo and G_no are defined as:

$$G = \frac{< |S_{21}|^2 >}{(1 - | < S_{11} > |^2)(1 - | < S_{22} > |^2)},$$ (2)

where S_{21} is the transmission coefficient measured between two efficient antennas in the reverberation chamber and S_{11} and S_{22} are the reflection coefficients of the two antennas. Here, the radiation efficiencies of the antennas are assumed to be unity as we are interested in relative ACS measurements.

Carlberg also includes a method [3] to calculate the error in the ACS measurement. Gifuni has described a method of calculating the uncertainty of ACS measurements in [4] using a different method from that in [3]. [4] also shows that when considering measurement uncertainty the position of the object when in the reverberation chamber is important due to the field
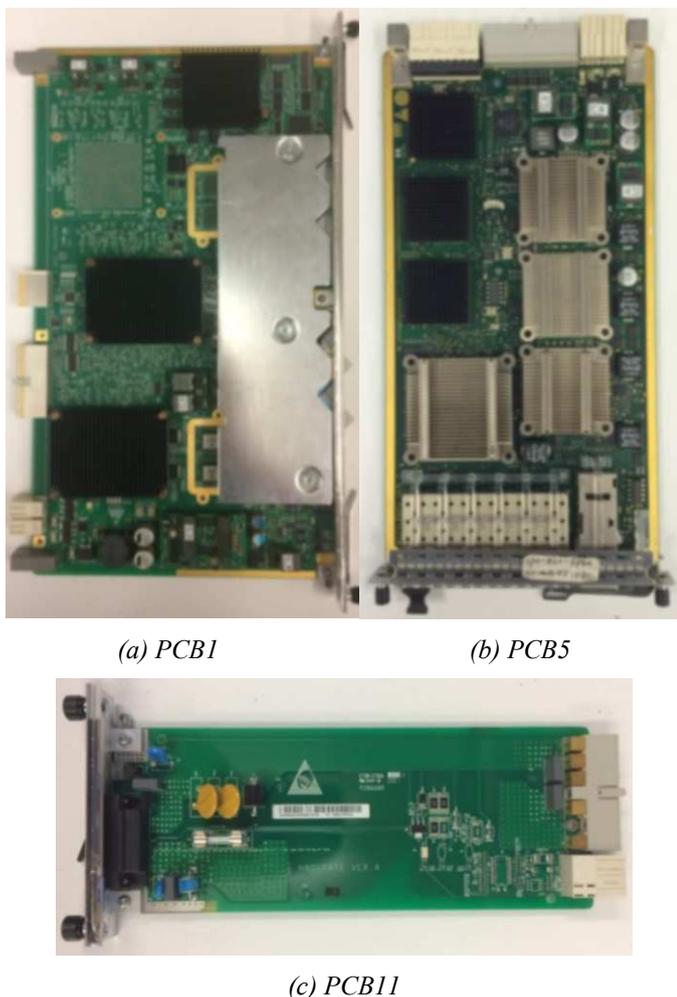
(a) PCB1   *(b) PCB5*

(c) PCB11

Fig. 1. Photographs of each of the PCBs tested.

uniformity. [5] presents an uncertainty model for ACS measurements and which was applied onto a set of PCBs in [2], some of which are the PCBs measured during the experiments described in this paper.

III. PCBs UNDER TEST

Three PCBs were measured during these experiments and are shown in Fig. 1. These PCBs were taken from an Information and Communication Technology (ICT) system and have the identification codes PCB1, PCB5 and PCB11. The PCBs PCB1 and PCB5 have dimensions of 365 mm × 210 mm × 20 mm and 283 mm × 145 mm × 15 mm respectively. Each has a variety of different components on it, including connectors, integrated circuits, passive components and heat sinks. PCB11 is a smaller board and has dimensions of 210 mm × 80 mm × 20 mm. It also has fewer components than the other two boards.

PCB1 was used for the majority of the measurements. PCB11 was used for the measurement of a PCB on its side in the centre of the chamber; away from the walls. This board was used rather than PCB1 as due to the front plate's larger size this

PCB could be balanced on its long edge easily without it falling over. PCB5 was used for the measurements where the PCB was placed parallel to the wall. This board was used as it has lower profile components on one side which allows the board to be slotted into a piece of polystyrene to prevent it from falling over during testing.

IV. MEASUREMENT SET UP AND METHODOLOGY

A diagram of the measurement setup is shown in Fig. 2 and a photograph looking through the open top of the reverberation chamber is shown in Fig. 3. All of the ACS measurements were carried out in this reverberation chamber which has dimensions of 0.6 m × 0.7 m × 0.8 m. A mechanical stirrer driven by a stepper motor and controlled by a PC external to the reverberation chamber, was used to stir the chamber, using 100 positions uniformly spaced over one rotation. A full set of S-parameters between two monopole antennas was collected using a vector network analyser (VNA). 10,001 measurement points were taken over the frequency range of 2 GHz to 20 GHz with a sweep time of 4.5 seconds. In order to increase the number of independent samples available, frequency stirring was applied to the measurement data using a bandwidth of 50 MHz. The PCBs were supported above the stirrer in the working volume of the reverberation chamber using a polystyrene sheet and smaller pieces of polystyrene were used to support the PCBs in position during measurements.

In order to calculate the ACS of the PCB in each position and orientation two measurements are required. The first is a reference measurement with no PCB in the chamber which was carried out once on each day measurements were taken. The second is a measurement with the PCB in the chamber for each location and orientation position.

A validation measurement has been carried out for the measurement procedure using objects with a known ACS [5]. The ACS uncertainty for this measurement is estimated to be ±15%.
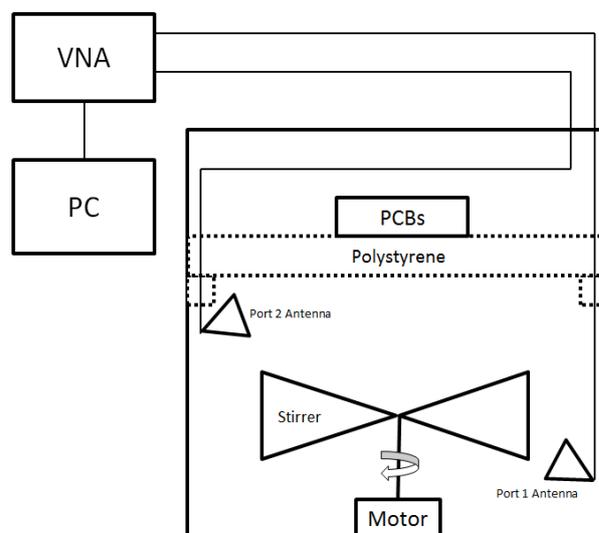

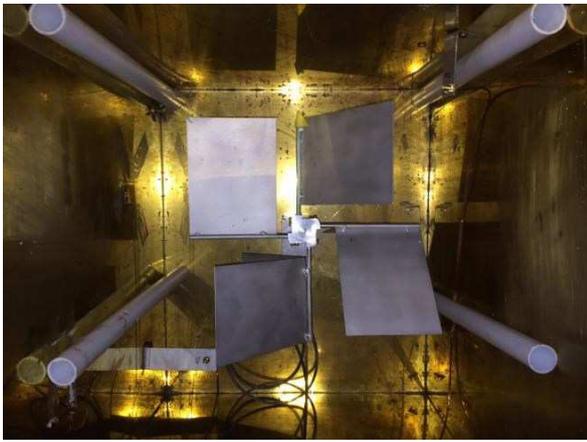Fig. 2. Side view of the ACS measurement setup.

Fig. 3. View from above (plan) of the reverberation chamber setup showing the stirrer in the centre, plastic supports for the polystyrene in each corner and antennas in the bottom left and top right.

TABLE I. PCB MEASUREMENT POSITIONS

| Position Number	Position	PCB
1	Centre	PCB1 PCB5 PCB11
2	Centre 90° clockwise	PCB1
3	Centre upside down	PCB1
4	50 mm left	PCB1
5	50 mm right	PCB1
6	100 mm right, PCB edge against wall	PCB1
7	220 mm down, PCB edge against wall	PCB1
8	Centre on side, perpendicular to polystyrene sheet	PCB11
9	10 mm away from wall, back facing	PCB5
	10 mm away from wall, front facing	PCB5
10	20 mm away from wall, back facing	PCB5
	20 mm away from wall, front facing	PCB5

A number of measurements were made with the PCBs in different positions and orientations. Each PCB was measured lying flat, with the component side of the board facing up, in the centre of the polystyrene. These measurements were used as reference measurements for comparison to the locations close to the walls and other measurement positions and orientations. PCB1 was measured lying flat on the polystyrene in different positions including component side up, component side down, rotated 90° and positioned with one of its edges next to the wall. PCB11 was measured balanced on one edge in the centre of the polystyrene. Two small pieces of polystyrene were placed either side of the board to keep it upright. PCB5 was measured positioned parallel to the chamber wall 10 mm from the wall and 20 mm from the wall. This was carried out with both the back of the PCB (flat side with fewer and smaller components) and front of the PCB (component side) facing the reverberation chamber wall. The long side of PCB5 which has smaller and fewer components was placed in a slot in a piece of polystyrene in order to keep the board in position during the measurements. A full list of measurement positions is given in
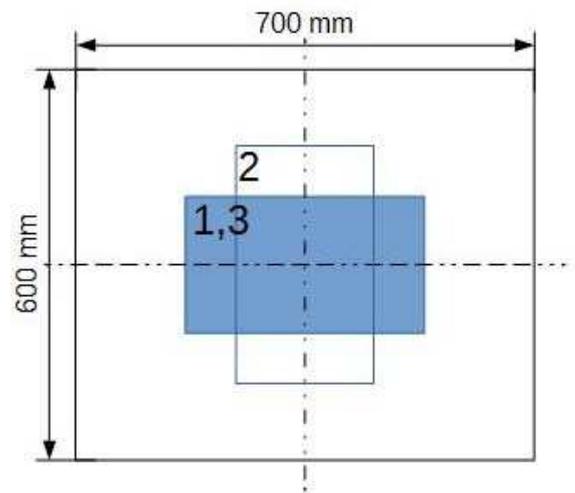
(a) Positions 1-3, board on centre line
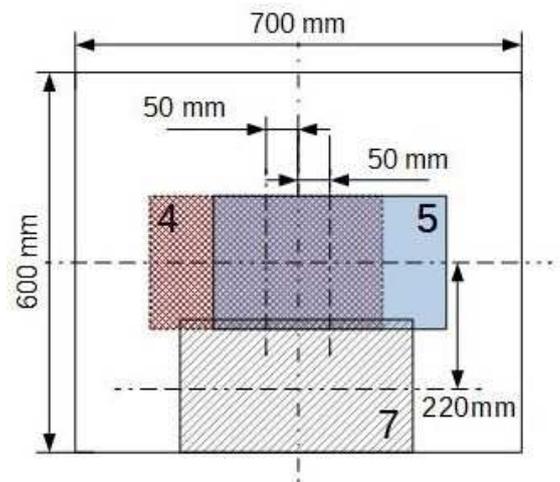
(b) Positions 4, 5 and 7, boards displaced 50mm from centre line and 220mm below centre line
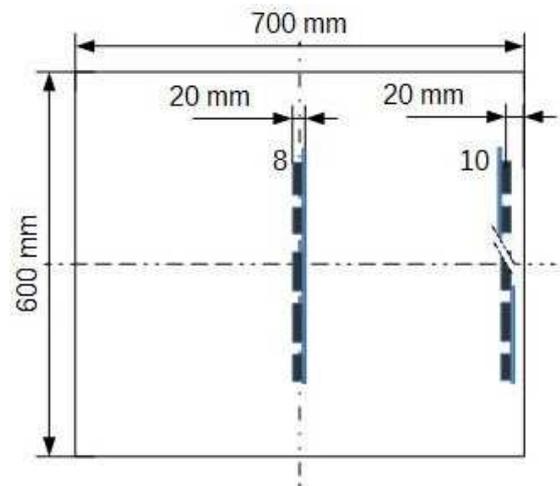
(c) Positions 8 and 10 with board on edge.

Fig. 4. Plan view of the different PCB positions in the reverberation chamber (see Table I).

Table I, the positions are given relative to the central reference position described above. Fig. 4 shows a plan view of the PCB positions inside the reverberation chamber.

V. RESULTS

The measured ACS of PCB1 in different positions and orientations in the reverberation chamber is shown in Fig. 4, Fig. 5 and Fig. 6. For the central reference measurement shown in these figures the ACS rises from 5×10^{-3} m^2 at 2 GHz to 8×10^{-3} m^2 at 3 GHz and then decreases to 5×10^{-3} m^2 at 5 GHz. From 5 GHz to 20 GHz the ACS remains relatively flat.

Fig. 4 shows the ACS when the PCB is in different positions in the centre of the chamber; lying flat with the front side facing upwards (component side), rotated 90° and lying flat with the back of the PCB facing upwards. The graphs show that there is minimal change in ACS between the different measurement positions.

Fig. 5 shows the ACS when the PCB is positioned lying flat on the polystyrene in the centre position and then in two positions with one edge just touching the reverberation chamber wall. For the 100 mm right from the centre one short edge of the PCB is touching the wall. For the 220 mm down from the centre the front panel of the PCB is touching the wall. Again, it can be seen that there is little difference between the measurement positions even when the PCB is close to the reverberation chamber wall.

Fig. 6 shows the ACS when the PCB is moved to the left of the centre position by 50 mm and to the right of the centre position by 50 mm and 100 mm, the latter in the touching the wall position. As before, the ACS does not vary significantly between measurement positions.

Fig. 7 shows all results for PCB1 on one graph for comparison. All the graphs show that putting this PCB in different measurement positions in the chamber produces little change in ACS even when moved against the chamber wall; the ACS is independent of position and orientation in the chamber when this PCB is perpendicular to the chamber walls.
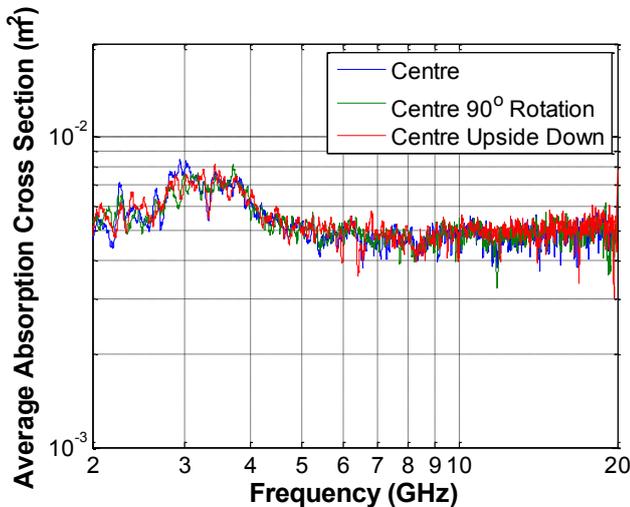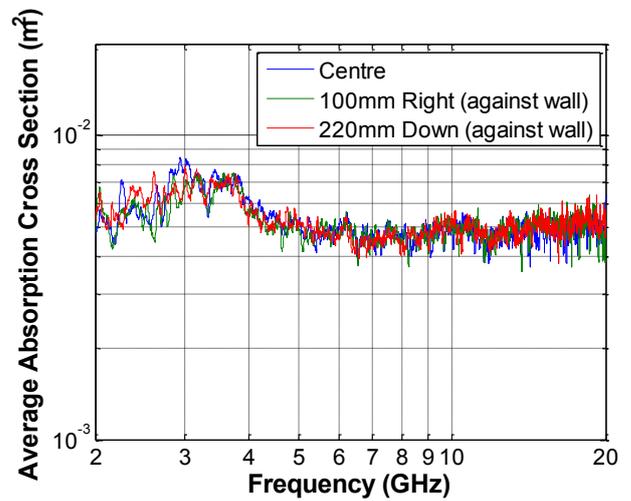

Fig. 6. Measured ACS of PCB1 placed in the centre of the polystrene and moved 100 mm right from the centre position so that the edge of the board is touching the reverberation chamber wall and 220mm down from the centre position so the front panel of the board is touching the chamber wall.
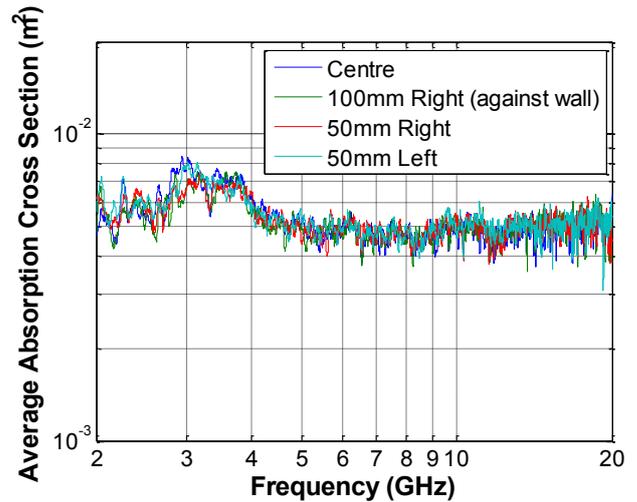

Fig. 7. Measured ACS of PCB1 placed in the centre of the polystrene and moved left 50 mm and right 50 mm and 100 mm.

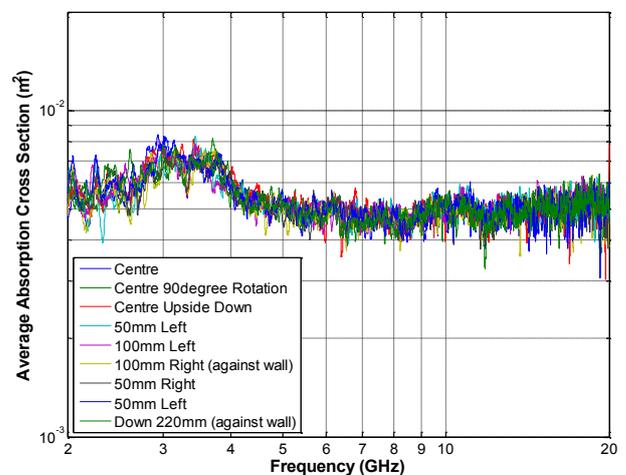Fig. 5. Measured ACS of PCB1 placed in the centre of the polystrene, rotated 90° and turned upside down.
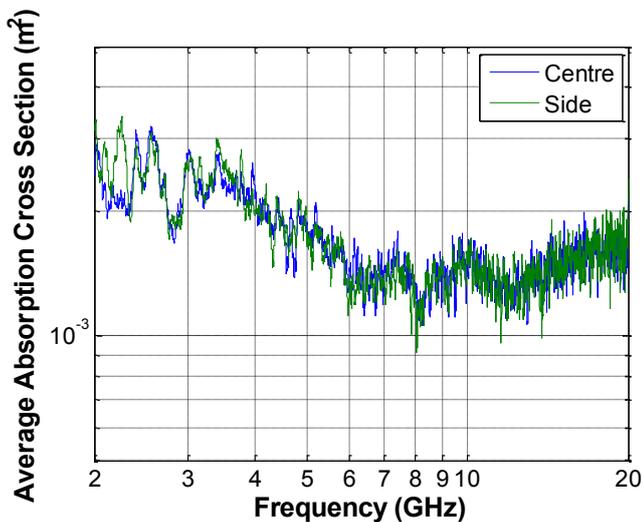

Fig. 8. Measured ACS of PCB1 in all positions

Fig. 9. Measured ACS of PCB11 placed in the centre of the polystrene horizontal (flat on polystyrene) and when the PCB is balanced vertically on its edge

Fig. 10. Measured ACS of PCB5 placed in the centre of the polystrene and when board is parallel to the reverberation chamber wall at different distances from the wall and with different faces of the PCB facing the wall.

The ACS of PCB11 is shown in Fig. 8. This is the situation where the PCB is stood on one of its long edges in the centre of the working volume of the chamber. The ACS for PCB11 in the centre position varies between 10^{-3} m^2 and 3×10^{-3} m^2. The ACS of this PCB is smaller than that of PCB1 as the PCB is smaller. Again, the ACS of the PCB does not change significantly when positioned differently.

Fig. 9 shows the ACS of the board PCB5 in each of its measurement positions. The board PCB5 was measured in the centre of the working volume of the reverberation chamber and then in four positions close to and parallel to the wall of the reverberation chamber. These positions were 10 mm and 20 mm from the wall with the back and the front (component side) of the PCB facing the wall. When the back of the PCB was facing the wall little difference was seen in ACS compared with the ACS in the centre positions for both the 10 mm and 20 mm distances from the wall. However, when the front of the PCB was placed facing the reverberation chamber wall the ACS was observed to be lower than the centre and back facing measurements. The distance between the PCB and wall also affected the measured ACS.

For the case where the front of the PCB is facing towards the wall at a distance 20 mm away the ACS is generally between 3×10^{-3} m^2 and 5×10^{-3} m^2 from 2 GHz to 4 GHz. This compares to between 3×10^{-3} m^2 and 8×10^{-3} m^2 when the board is in the centre position or with the back facing the chamber wall. This is a reduction in ACS of 10% to 50% in this frequency range. After 4 GHz the ACS is generally 10% less than the centre position.

When the PCB is 10 mm away from the chamber wall and with the front facing it the ACS is significantly lower than that of the centre and back facing positions from 2 GHz to 8 GHz. Between 2 GHz and 3 GHz it is reduced by between 20% to 50%. After 8 GHz the ACS becomes closer to the centre ACS but is still between 10% to 20% lower. In both cases, the ACS is reduced by approximately 40% at 3 GHz and between 3 GHz
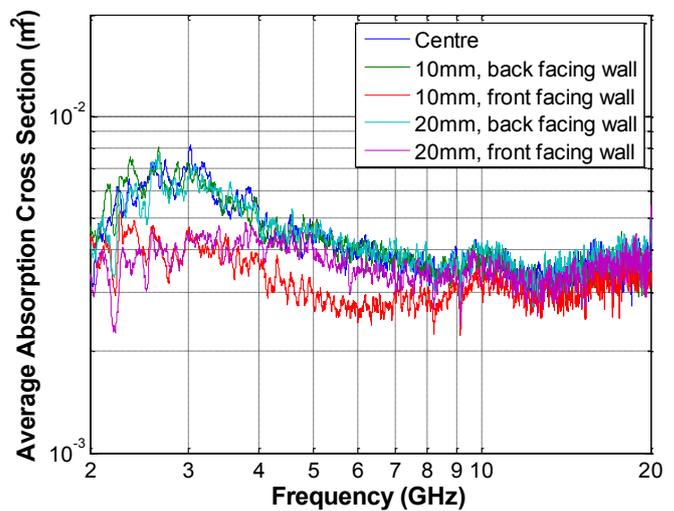
and 8 GHz the 20 mm case is reduce by 30% from the ACS measured in the centre position.

Between 2 GHz and 3.5 GHz the front facing PCB ACS is approximately the same when the PCB is both 10 mm and 20 mm distance from the wall. After 3.5 GHz and up to around 8 GHz the difference between the ACS at 10 mm and 20 mm distance from the wall becomes more significant. A distance of 10 mm is a quarter wavelength at 7.5 GHz and a distance of 20 mm is a quarter wavelength at 3.75 GHz. These two frequencies are when the difference between the 10 mm and 20 mm ACS is greatest. It might be expected that this would actually occur at a difference of half a wavelength. As the reverberation chamber wall is a good conductor and the PCB side is absorbing this could be explained by image theory.

VI. CONCLUSIONS

The ACS of three different PCBs in a number of different positions and orientations in a reverberation chamber has been measured over the frequency range 2 GHz to 20 GHz. The results show that when the PCB is perpendicular to the reverberation chamber wall, changing the measurement position has minimal effect on the measured ACS, even when positioned against the chamber wall. Again, when placed parallel to the wall with the back of the PCB facing the wall there is little effect on the ACS. When placed parallel to the wall with the components on the front of the PCB facing the wall the ACS is significantly reduced. In this situation the ACS can be reduced by up to 30% of the ACS of the board placed in the centre of the working volume in the chamber.

It might be expected that the measured ACS of a board would change as it is brought close to the chamber walls due to the change in field distribution and possible shadowing of one side of the PCB from the chamber. Usually it is advised to keep objects under test at least a quarter wavelength (37.5 mm at 2 GHz) away from the chamber walls in order to remain within the working volume of the reverberation chamber. These

results show that when the PCB is perpendicular to the wall the ACS is not affected. When the front of the PCB is facing the wall the ACS is reduced. At frequencies below which the distance between the PCB and the chamber wall is a quarter of a wavelength the ACS is most reduced. At frequencies above this the ACS becomes closer to the centre position PCB ACS.

Further work to be carried out includes additional investigation into the effects when close to the reverberation chamber wall. This includes making more measurements at different distances from the wall when the PCB is parallel to it. When the back and front of the PCB are facing the wall different results are observed. Measuring the ACS of one side of the PCB at a time may show that one side of the PCB is more absorbing than the other. A segmented power balance analysis could also be carried out in the situation when the PCB is parallel to the wall.

The results show that when measuring the ACS the PCBs position in the reverberation chamber is unimportant unless the front, component side is close and parallel to the chamber wall. When the ACS of an object in an enclosure is less than expected, such as when the front of the PCB is facing the chamber wall, the internal EM field of the enclosure is greater than that expected. Therefore, the shielding effectiveness of the enclosure is reduced. A greater understanding of the ACS of PCBs in enclosures is important as it allows engineers to more accurately predict shielding effectiveness when designing equipment.

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