An Experimental Study of the Effects of Internal Loading on the Measured Shielding Effectiveness of Printed Circuit Board Shields

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***Abstract*— The measurement of shielding effectiveness of printed circuit board shields can be undertaken with the shields connected to a measurement jig installed in a reverberation chamber. The internal loading of the printed circuit board shield is not normally accounted for in Shielding Effectiveness measurements. The measurement jig used in this paper has internal loading in the form of a stripline that is used to measure the energy coupled into the shield. Normally this stripline is terminated in matched loads. In this paper we illustrate the effects on the measured Shielding Effectiveness of the printed circuit board shield of changing the terminations of the internal stripline and of the addition of extra absorbing material into the shield.**

Keywords*— *printed circuit board shields, reverberation chamber measurements

I. Introduction

This paper follows our previous papers on printed circuit board level shields (PCBS) [1], [2], [3] and reports aspects of our work on the IEEE Project P2716 [4] the output of which is a document describing various methods of measuring the Shielding Effectiveness (SE) of a PCBS. In [1] we described a set of SE metrics for use in the microwave frequency range where the external environment of the PCBS is likely to be reverberant. In [2] we demonstrated that the SE metrics were representative of the SE observed when the PCBS were deployed in a variety of outer enclosures. In [3] we showed that the PCBS can be installed onto the circuit card measurement board using silver conducting paint (SCP) rather than solder enabling rapid and non-destructive connection and disconnection of the PCBS. In this paper we report on measurements demonstrating the effects of variability on the internal contents of the PCBS on the measured SE.

Conventional SE measurement standards, for example [5] take no account of the internal contents of the shield. In reality the internal contents of a shield in use have an effect on the internal field structure and the contents are likely to absorb the electromagnetic energy which penetrates into the shield through the various apertures and joints in its structure. The protection offered by the shield is as much a function of the absorption by its internal contents as it is the of structure of the shield. This was demonstrated in [6] for shields large enough for both the external environment and the interior of the shield to exhibit reverberant properties. The SE of the shield is shown to be

$$SE = \frac{S_0}{S_1} = \frac{\langle\sigma^t\rangle + \langle\sigma_1^a\rangle}{\langle\sigma^t\rangle} \tag{1}$$

where

$$\langle\sigma_1^a\rangle = \langle\sigma_{1enc}^a\rangle + \langle\sigma_{1ant}^a\rangle + \langle\sigma_{1cont}^a\rangle \tag{2}$$

In (1) and (2) above $\langle\sigma^t\rangle$ is the total average transmission cross-section of all the apertures in the shield enclosure, $\langle\sigma_1^a\rangle$ is the total average absorption cross-section of the shield enclosure contents comprising the absorption cross-sections of the internal walls subscript *enc*, the shield contents subscript *cont*, and the internal measurement antenna subscript *ant*. Here SE is defined in (1) by the ratio of S_o the average electromagnetic power density outside the shield and S_i the average power density inside the shield.

It is clear that the internal contents of the shield have a significant effect on its SE, increasing it from the value exhibited by an empty shield. However, as the energy absorbed into the shield internal contents is the interference problem, the contents of the shield cannot be ignored.

Equations (1) and (2) were derived for the situation where both the shield enclosure and its external environment are large enough to be reverberant. A PCBS is typically a smaller structure with linear dimensions of less than 100 mm and so will only be reverberant at frequencies in the tens of Giga Hertz range. In the frequency range considered here from 200 MHz to 20GHz the PCBS is not reverberant but may exhibit resonant behaviour. However, its external environment is still likely to be reverberant as accounted for in the metrics in [1].

Although the PCBS contents cannot be accounted for in the simple average way of (1) variability in the absorption behaviour of the contents will have an effect on the measured SE. In this paper we examine the effects of variable absorbing contents on the measured SE of a PCBS in a series of measurements performed using the measurement jig used in [1], [2], and [3].

II. The Printed Circuit Board Shield Shielding Effectiveness Measurement Jig

A. The Structure of the Jig

Fig. 1 shows an image of the PCBS SE measurement jig with a typical PCBS attached. The striplines external to the jig couple energy to a stripline in the shield interior, referred to as the shield stripline. This is shown in Fig. 2 which is the reference jig used for the unshielded coupling measurements. Each of the striplines is 25 mm long and has a characteristic impedance of 50 Ω. The centre to centre separation of each of the external striplines to the internal shield stripline is 50 mm. The striplines shown in Fig. 1 and Fig. 2 are terminated with SMA jacks on the other side of the jig circuit board. The centre conductors of the jacks go through plated through holes to the striplines.

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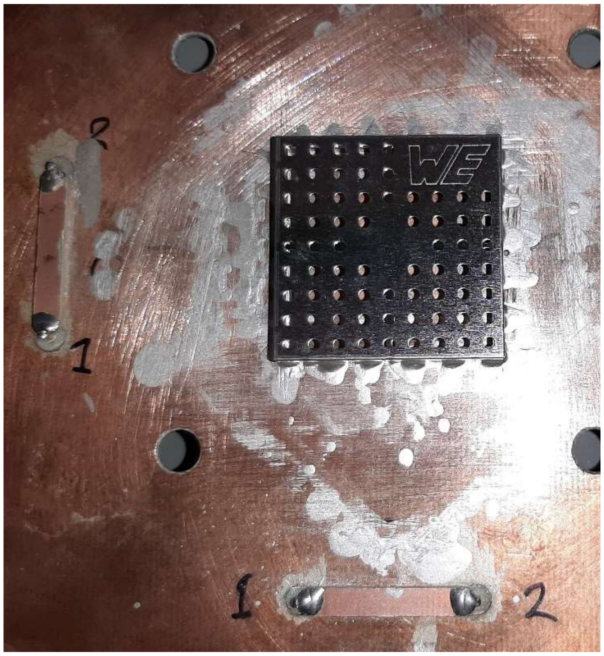

Fig. 1. Image of the PCBS SE measurement jig with a typical PCBS installed.

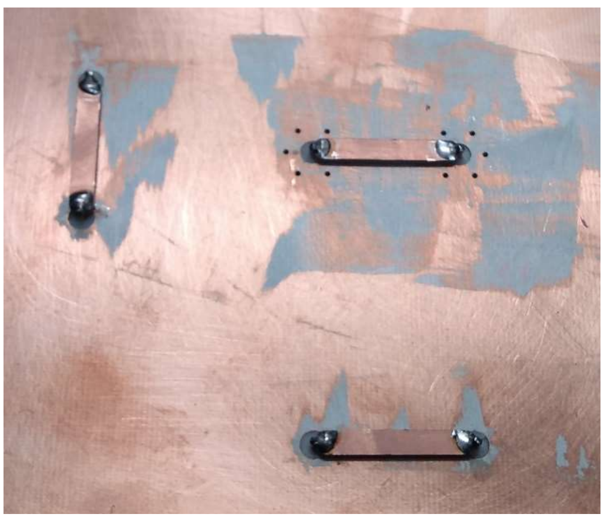

Fig. 2. Reference jig used for unshielded coupling measurements.

This prevents waves being launched from these centre conductors into the circuit board substrate providing an unwanted coupling path between the internal and external striplines. In Fig 2 extra plated through holes can be seen surrounding the internal stripline terminations.

B. *Internal Loading of the PCBS on the Jig*

In our previous work the external and internal striplines have always been terminated with 50 Ω loads. Typically, stripline end 1 (see the annotations on Fig. 1) is connected to a 50 Ω vector network analyser (VNA) port whilst stripline end 2 is connected to a 50 Ω load. The stripline inside the PCBS replicates the PCBS contents and internal energy is absorbed into the 50 Ω load and the 50 Ω VNA port. In work described in [1], [2], and [3] the striplines on the measurement jig were as shown in Fig.2. Here we have adopted two strategies to change the PCBS contents.

The first is to change the terminations on the internal shield stripline from 50 Ω to either a short circuit or an open circuit whilst retaining the 50 Ω VNA connection.

The second strategy is to install a block of carbon loaded foam (ECOSORB LS22) inside the shield to provide further added absorption. Fig. 3 shows an image of the shield with the block installed. The block fills the full depth and full width of the PCBS.

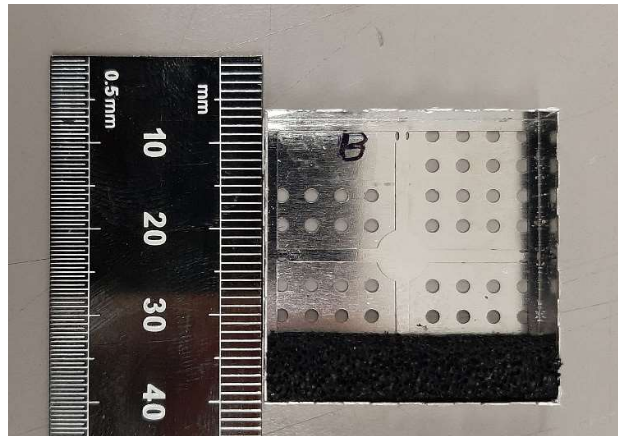

Fig. 3. LS22 absorber block installed in the PCBS.

III. Shielding Effectiveness Measurements

A. *Shielding Effectiveness Measurement Technique*

The SE measurements were performed according to the method described in [1] and [3]. The York reverberation chamber with dimensions of 2.3 m x 3.0 m x 4.7 m with a lower useable frequency of 200MHz is used to replicate the variability of the unknown external environment of the PCBS. One hundred stirrer positions over one rotation of the stirrer were used. The SE metric is the Point SE described in [1] where, at each frequency, the ratio is taken of every unshielded measurement to every shielded measurement for all the one hundred stirrer positions. The mean value of this metric is given in (3) where S_{21u} is the scattering parameter measured between the shield stripline VNA port and the external stripline VNA port with no PCBS present and S_{21s} is the scattering parameter measured between the shield stripline VNA port and the external stripline VNA port with the PCBS installed.

$$SE_{point(mean\ dB)} = \left\langle 10\, log_{10} \left|\frac{S_{21u}(n)}{S_{21s}(n)}\right|^2 \right\rangle \text{dB} \qquad (3)$$

It was demonstrated in [1] that there is no correlation between the shielded and unshielded measurements as a function of stirrer position. Thus all shielded measurements can be ratioed with all unshielded measurements to give a larger population for statistical analysis. This results in a total population of ten thousand SE ratios (100 unshielded measurements each ratioed with 100 shielded measurements) at each frequency. The results presented are the mean value as in (3) and the ±3 σ bounds of the population.

The same PCBS shown in Fig.1 and Fig. 3 was used in all the measurements presented in this paper. In each case the PCBS was attached to the measurement jig using SCP as described in [3].

B. *Shielding Effectiveness Measurement Results with Short Circuit and Open Circuit Loads*

Fig. 4 shows the SE measurement for the PCBS with 50 Ω loads on both the internal and external striplines on the measurement jig.

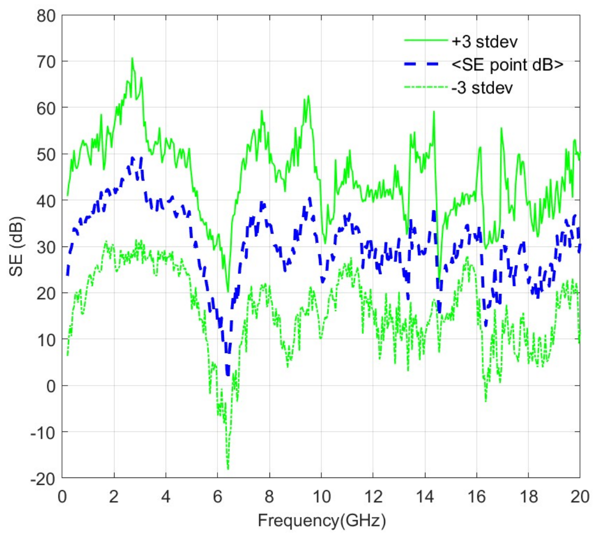

Fig. 4. Mean Point SE of the PCBS with 50 Ω Loads.

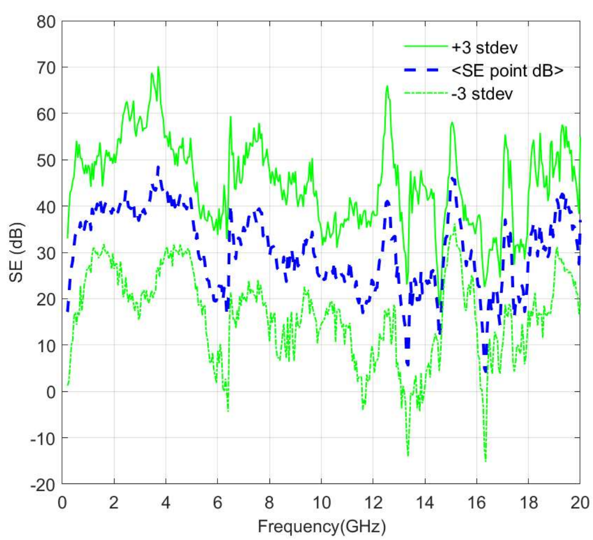

Fig. 5. Mean Point SE of the PCBS with an Open Circuit load on the Shield Stripline.

In Fig. 5 the effect of replacing the shield stripline 50 Ω load with an open circuit load is seen in the additional resonances exhibited in the mean point SE and the larger variability in the mean point SE.

With a short circuit load on the shield stripline, Fig. 6, a similar effect is seen to that of the open circuit load. Only the detail in the mean point SE is different.

For both short circuit and open circuit loads the overall level of SE is comparable to that of the 50 Ω load.

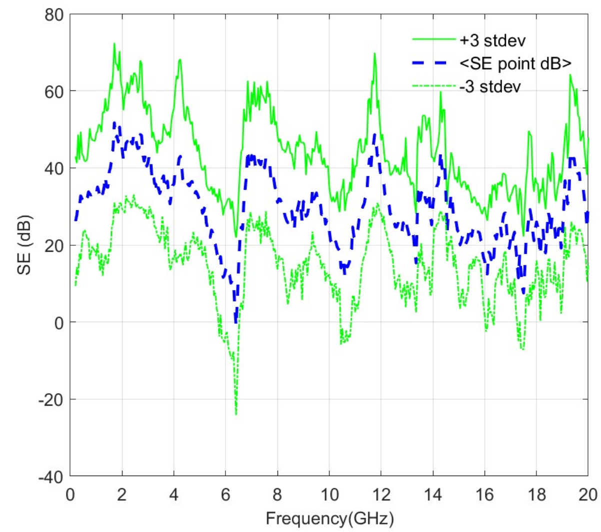

Fig. 6. Mean Point SE of the PCBS with a Short Circuit load on the Shield Stripline.

C. *Shielding Effectiveness Results with Added Absorber.*

In addition to the changing loads on the shield stripline, a block of LS22 absorber was introduced into the PCBS as shown in Fig. 3. The LS22 is located along one edge of the PCBS and the shield stripline is parallel to the edge with the LS22 block. The SE was measured with the LS22 block located between the shield stripline and the external parallel stripline (between) and also with the LS22 block located on the side of the shield stripline away from the external parallel stripline (far side). Comparison of Fig. 7 (far side) and Fig. 8 (between) with Fig. 4 shows evidence of enhanced SE expected by an increased internal loading of the shield.

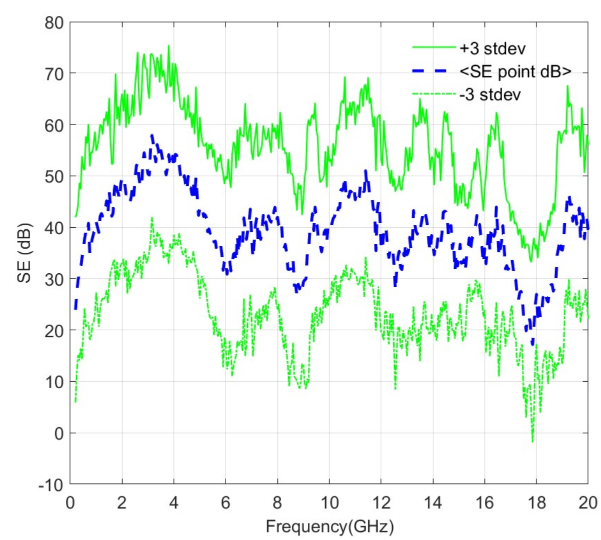

Fig. 7. SE measured with the LS22 Absorber block inside the PCBS with a 50 Ω load on the Shield Stripline (far side).

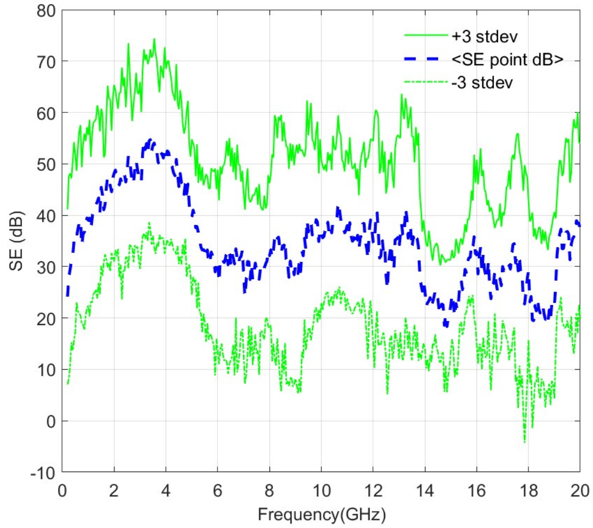

Fig. 8. SE measured with the LS22 Absorber block inside the PCBS with a 50 Ω load on the Shield Stripline (between).

Fig. 9 (between) and Fig. 10 (far side) show the effect of changing the interior stripline load to a short circuit on the SE of the PCBS with added absorber. As with the data shown in Fig 5 and Fig. 6 the changes to the SE are limited to enhanced resonant behaviour. The overall enhanced level of SE observed for the 50 Ω load is maintained.

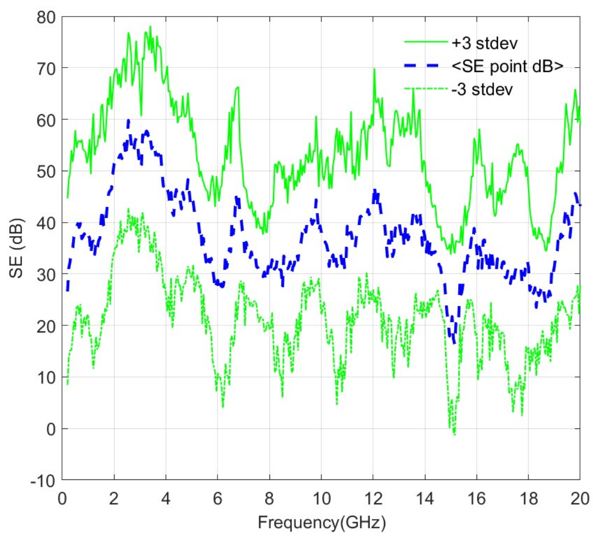

Fig. 9. SE measured with the LS22 Absorber block inside the PCBS with a SC load on the Shield Stripline (between).

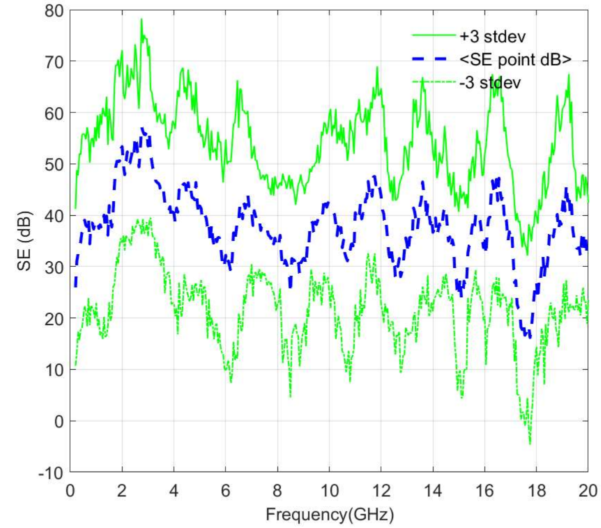

Fig. 10. SE measured with the LS22 Absorber block inside the PCBS with a SC load on the Shield Stripline (far side).

Fig. 11 shows the comparison between the comparison between the SE of the PCBS with and without added absorber on the far side of the shield stripline. Fig. 12 shows comparable data for the added absorber between the shield stripline and the external stripline. In both cases the added absorber clearly shows an increase in SE over all but the highest part of the frequency range.

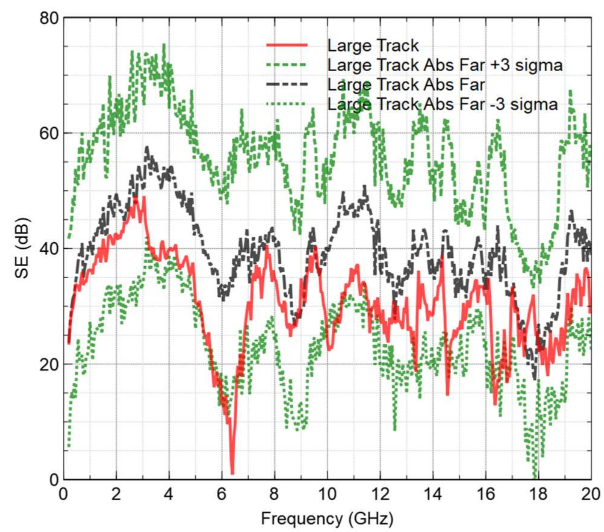

Fig. 11. Comparing SE for the jig with absorber on the far side of the shield stripline in the PCBS and with no absorber in the PCBS with a 50Ω load on the shield stripline in both cases

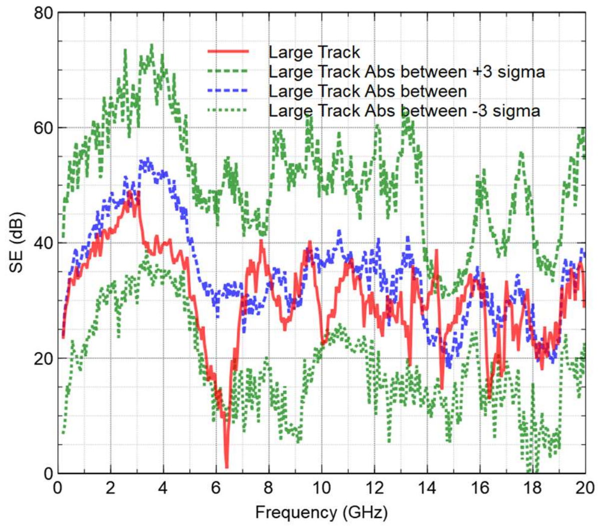

Fig. 12. Comparing SE for the jig with absorber between the shield stripline in the PCBS and the external stripline with no absorber in the PCBS with a 50Ω load on the shield stripline in both cases

IV. Discussion and conclusions

The results shown in Fig. 4 to Fig. 12 indicate that the variation of internal loading of a PCBS does have an effect on its measured SE. Equation (1) indicates that increased loading should increase the measured SE. This is well established in a number of papers, for example [6]. However, the shield used in [6] is large enough to exhibit reverberant properties over the whole frequency range. The PCBS used in these measurements has dimensions of 32 mm square and 6 mm deep and is too small to exhibit true reverberant properties.

The principal effect of changing the shield stripline load from 50 Ω to an open or short circuit is to introduce greater variability in the measured SE shown in the form of extra resonances. The overall level of the SE across the frequency range is comparable across all loads, the added variability masking any trends

The theoretical approach described by (1) assumes that the internal energy density in the shield is measured and that the absorption cross sections of the shield walls and contents are implicitly independent of this measurement. In the measurements presented here the measurement of the electromagnetic energy within the PCBS is done by the shield stripline which is also the only absorbing contents other than the PCBS wall.

When the LS22 block is introduced into the PCBS there is an observable increase in measured SE as predicted by (1). The upper measured frequency is lower than that required for reverberant behaviour of the PCBS so this result indicates that the increased SE with added internal shield loading is present below the reverberant frequency range. This effect has not been observed before in this context.

At this initial experimental stage, the quantitative electromagnetic properties of the LS22 absorber have not been considered. The data do however indicate the direction of future work which will include the numerical modelling of this scenario to examine the relationship between the internal loading and measured SE accounting for the contribution to the loading provided by the internal energy measurement stripline. Evaluation of the electromagnetic absorbing properties of a range of typical components that are installed in PCBSs will be undertaken to facilitate this work.

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