# On the Improvement of the Standard on the Shielding Effectiveness Measurements of Gaskets and Materials in Reverberation Chambers

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# SHIELDS AND FLAT SHIELDS

Strictly, a shield however implies a close volume (enclosure), which encloses electric devices and circuits. The shielding caracteristics of flat shields (slabs, fabrics, etc. ) are of interest as they are used to assemble enclosures and how gaskets.

# DEFINITION OF THE SHIELDING EFFECTIVENESS FOR FLAT SHIELDS OF INFINITE SIZE

In the abstract, the shielding effectiveness (*SE*) of a flat shield of the infinite size, where a plan wave inpinges from one of the two semi spaces, is defined by the ratio of the transmitted field to incident one:

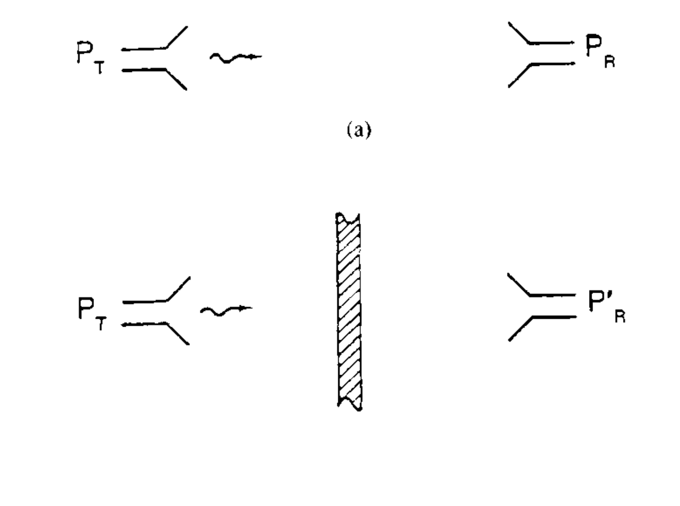
$$SE = -20\log_{10}\left|\frac{\hat{E}_t}{\hat{E}_i}\right|$$

The abstraction is due to energetic reasons.

# DEFINITION OF THE SHIELDING EFFECTIVENESS OF THE FLAT SHIELDS - REAL CASES OF FLAT SHIELDS

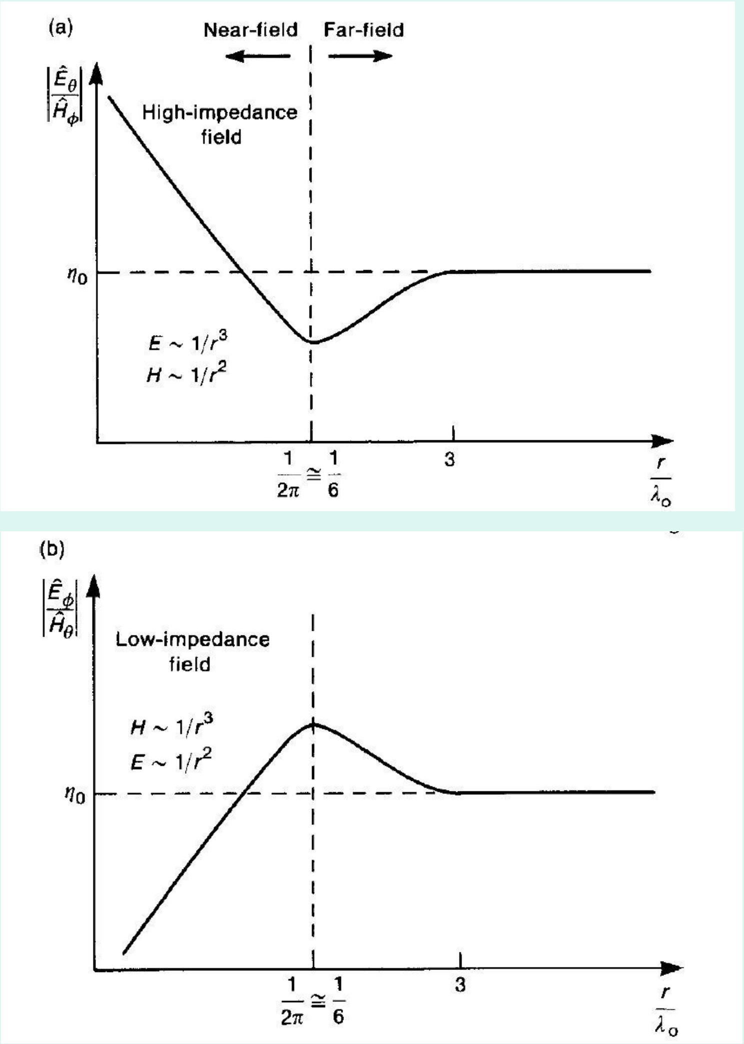
On the other hand, results from two antenna, separated by a real shield are not reliable, especially for high values of the SE.

- Note that if the antennas are close to the shield the effect of the edge scattering is reduced, but the measurement could be made in near field. In this case, the measured received powers have to adequately be interpreted.
- The configuration of the measurement system (sample size, antenna position) makes clear the field conditions. However, the standardization makes  measurements comparable.




$$SE = 10\log\frac{P_R}{P'_R}$$

# WAVE IMPEDANCE




Wave impedance of (a) the electric (Hertzian) dipole and (b) the magnetic (loop) dipole.

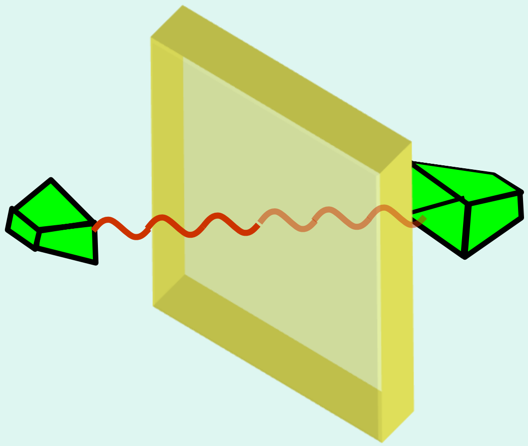
# DEFINITION OF THE SHIELDING EFFECTIVENESS OF THE FLAT SHIELDS

The SE depends on the incidence angle and the polarization, which are not a priori known in the real world.

There are several techniques to measure the SE of flat shields.

# MAIN TECHNIQUES OF MEASUREMENT FOR SHIELDING EFFECTIVENESS OF FLAT SHIELDS

1. Shield between two antennas in an Anechoic chamber (AC) or in Open Area Test Site (OATS)



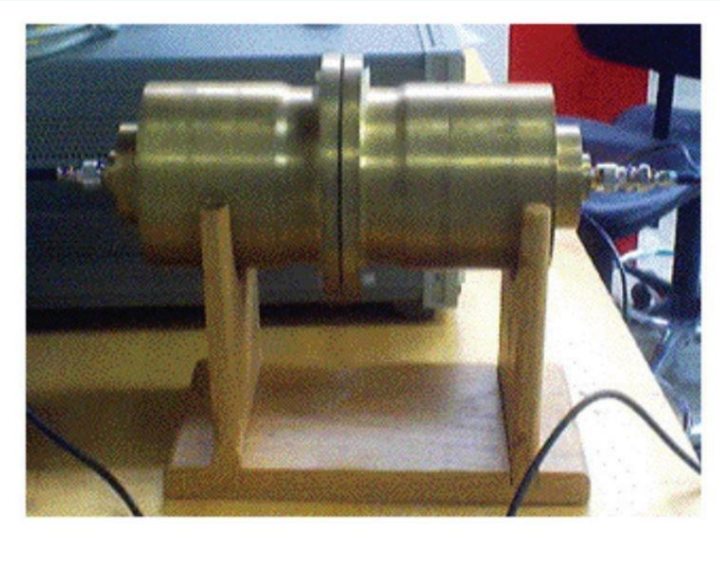
- Disadvantages: 1) measurements for small sample give serious consquences for high values of SE; 2) poor agility in incidence angle and polarization.

- Advantages: 1) simple interpretation of results; 2) range of frequency is the same as that of the AC including the antennas.

# MAIN TECHNIQUES OF MEASUREMENT FOR SHIELDING EFFECTIVENESS OF FLAT SHIELDS

1. Coaxial Cable Fixture:

Flanged Circular Coaxial Transmission-Line Holder



- Disadvantages: 1) limitated size of the sample; 2) no agility in incidence angle and polarization; 3) edge issue (it is reduced by the flange).
- Advatages: 1) simplicity of measuremnets; 2) good measurement dynamic range (MDR).

# MAIN TECHNIQUES OF MEASUREMENT FOR SHIELDING EFFECTIVENESS OF FLAT SHIELDS

## 3. Dual TEM Cells

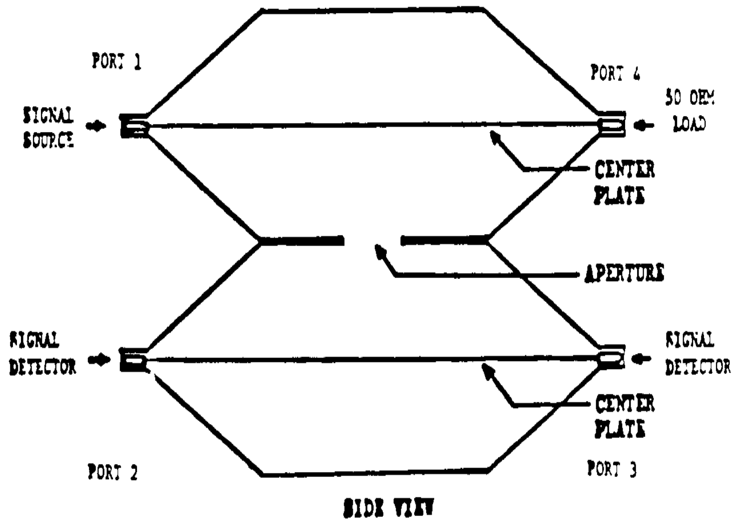


Fig. 1. The dual TEM cell.

Frequency range limited to that of the TEM cells (Low frequencies). The aperture is small with respect to the working wavelenght; therefore, the electric and magnetic coupling are different. However, both they can be meaesured. It is equivalent to measurements in near-field, which can also be considerably different from those in far-field.

# MAIN TECHNIQUES OF MEASUREMENT FOR SHIELDING EFFECTIVENESS OF FLAT SHIELDS

3. Dual TEM Cells;

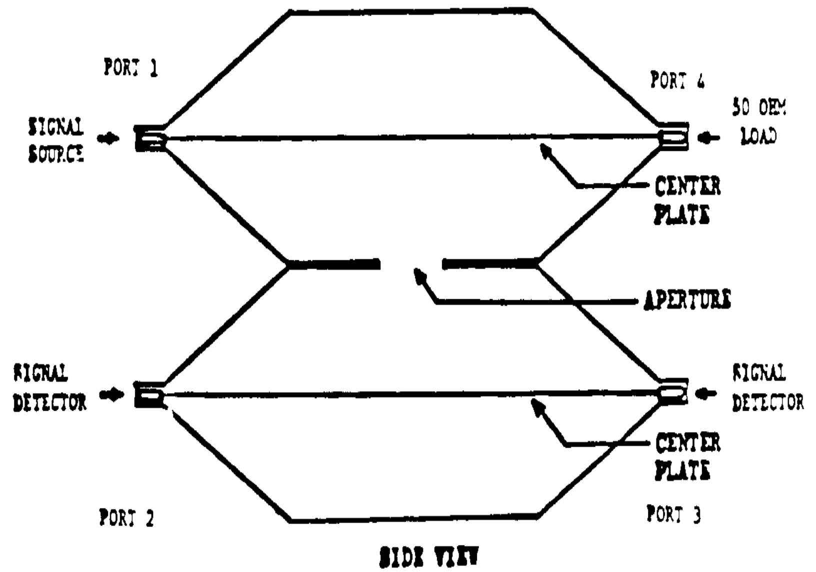
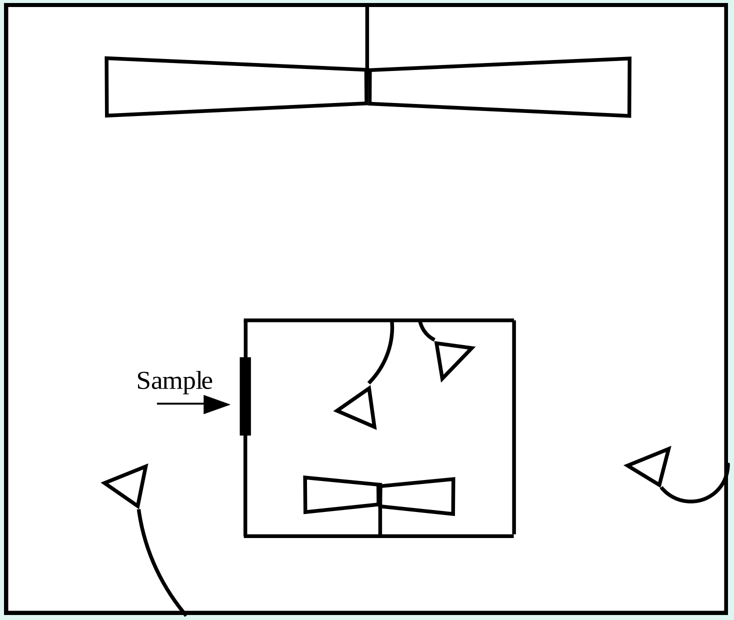



Fig. 1. The dual TEM cell.

- Disadvantages: 1) edge issue; 2) limited frequency range (high mode excitation), 2) low angle of incidence.
- Advantages: near-field measurements of electric and magnetic fields.

# MAIN TECHNIQUES OF MEASUREMENT FOR SHIELDING EFFECTIVENESS OF FLAT SHIELDS

4. Nested Reverberation Chambers and contiguous chambers.




- Disadvantages: edge issue, frequency rage limited to that of the chambers.
- Advantages: realistic conditions of measurements (incidence angle, polarization, and amplitude are random; so, it can be seen as a max agility for incidence angle, polarization and amplitute).

The aperture is electrically large in all cases of measurements of SE of gaskets and material using RCs.

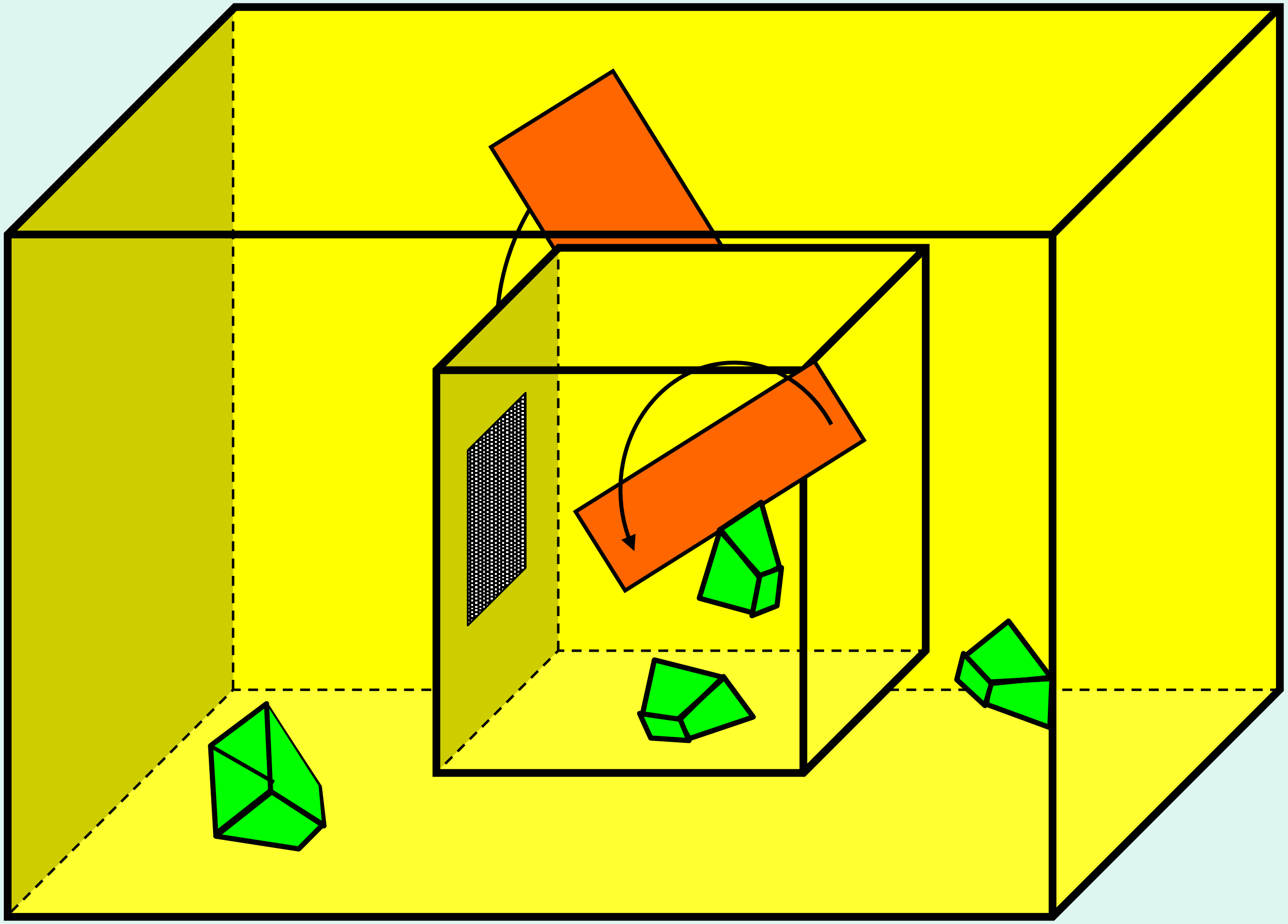
# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

- Inside reverberation chambers the field is on average uniform and isotropic. It emulates a realistic enviornment and is suitable for several EMC measurements [IEC 61000-4-21], including those of SE of gaskets and materials.

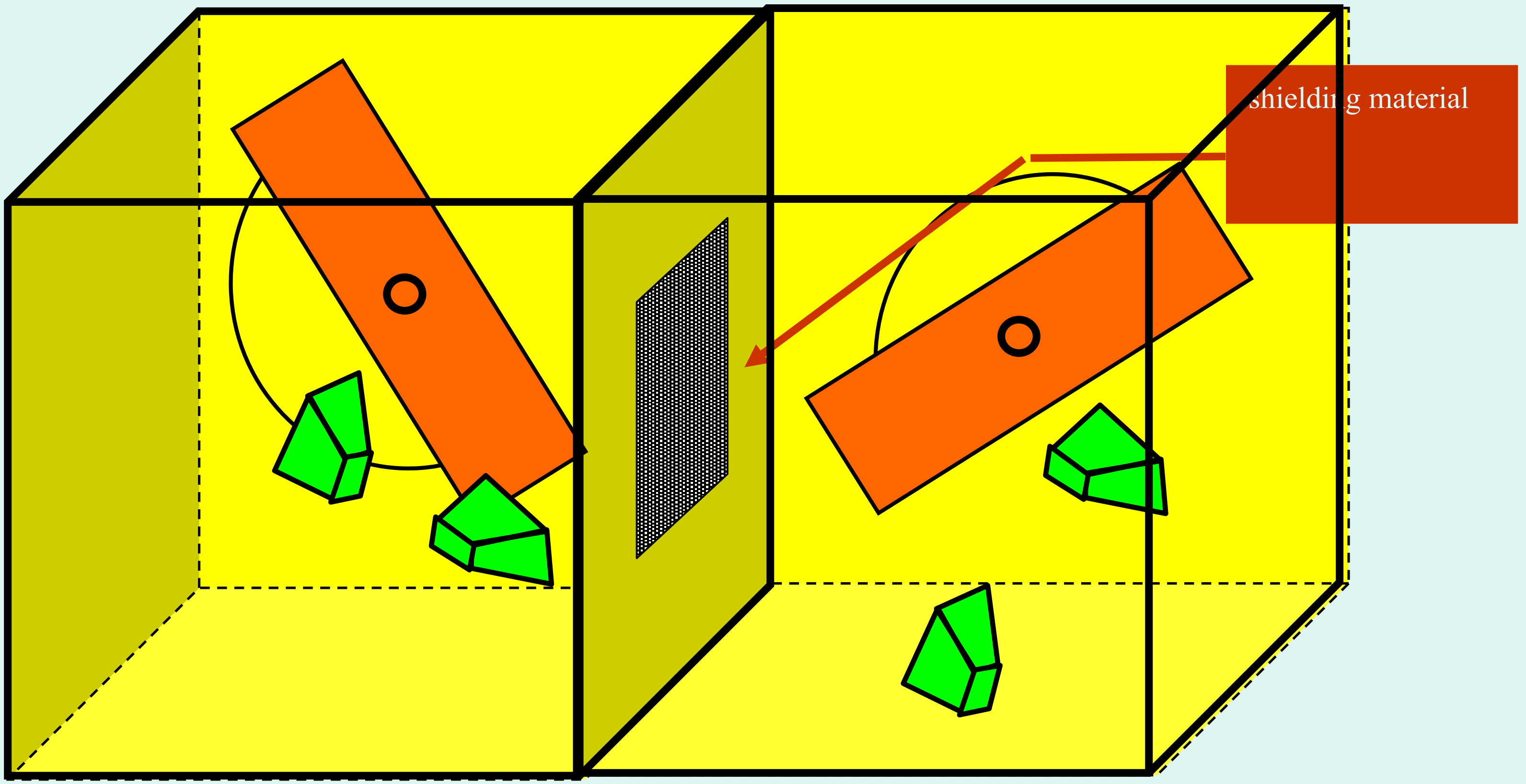
# Annexes in the standard IEC 61000-4-21

- **Annex A (Informative) Reverberation Chamber Overview**
- **Annex B (Normative) Reverberation Chamber Calibration Mode-Tuned**
- **Annex C (Normative) Reverberation Chamber Calibration Mode-Stirred**
- **Annex D (Normative) Electromagnetic Immunity Testing Procedures**
- **Annex E (Normative) Electromagnetic Emissions Testing Procedures**
- **Annex F (Informative) Shielding Effectiveness Measurement Procedures for cables, connectors, waveguides and passive microwave components**
- **Annex G (Informative) Shielding Effectiveness Measurements of Gaskets and Materials**
- **Annex H (Informative) Shielding Effectiveness Measurements of Enclosures**
- **Annex I (Informative) Antenna Efficiency Measurements**
- **Annex J (Informative) Direct Evaluation of Reverberation Performance using Field Anisotropy and Field Inhomogeneity Coefficients**
- **Annex K (Informative) Measurement uncertainty for chamber validation – Emission and immunity testing**

# NESTED REVERBERATION CHAMBERS SYSTEM



# CONTIGUOUS REVERBERATION CHAMBERS SYSTEM



# LOW USABLE FREQUENCY

Lowest usable frequency (LUF) is calculated according to the condition of at least 60 possible modes for the fixture.

$$N(f) = \frac{8\pi}{3} V \frac{f^3}{c^3}$$

$$f_{LUF} = c\left(\frac{90}{4\pi}\frac{1}{V}\right)^{\frac{1}{3}}$$

- If the fixture has a cubic volume, whose side is 70 cm, then LUF is about 825 MHz.
- If the fixture has a cubic volume, whose side is 100 cm, then LUF is about 580 MHz.

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

Before 2003, two uncorrect models were used for shielding effectiveness measurements: $SE_1$ and $SE_2$.

$$SE_1 = SE_{fixt,s} = -10\log\left(\frac{P^o_{rx,i,s}}{P^o_{rx,o,s}}\right)$$

$$SE_2 = 10\log\left(\frac{P^o_{rx,o,s}}{P^o_{rx,i,s}}\right) + 10\log\left(TFVF\,2\right)$$

$$= 10\log\left(\frac{P^o_{rx,o,s}}{P^o_{rx,i,s}}\right) + 10\log\left(IL_{fixt,s}\right)$$

Text fixture validation factor

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

From 2003, it was introduced the model SE3. It is defined in terms of average transmission cross sections both with sample and with no sample in the aperture (electrically large aperture in all cases), which are denoted by $\sigma_{t,s}$ e $\sigma_{t,ns}$, respectively.

The model is valid when the isolation with no sample in the aperture is greater or equal than 10 dB.

$$SE_3 = -10\log_{10}\left(\frac{\sigma_{t,s}}{\sigma_{t,ns}}\right)$$

$$=10\log\left(\frac{P_{r,o,s}}{P_{r,in,s}}\frac{P_{rQ,in,s}}{P_{tx,in,s}}\frac{P_{r,in,ns}}{P_{r,o,ns}}\frac{P_{tx,in,ns}}{P_{rQ,in,ns}}\right)$$

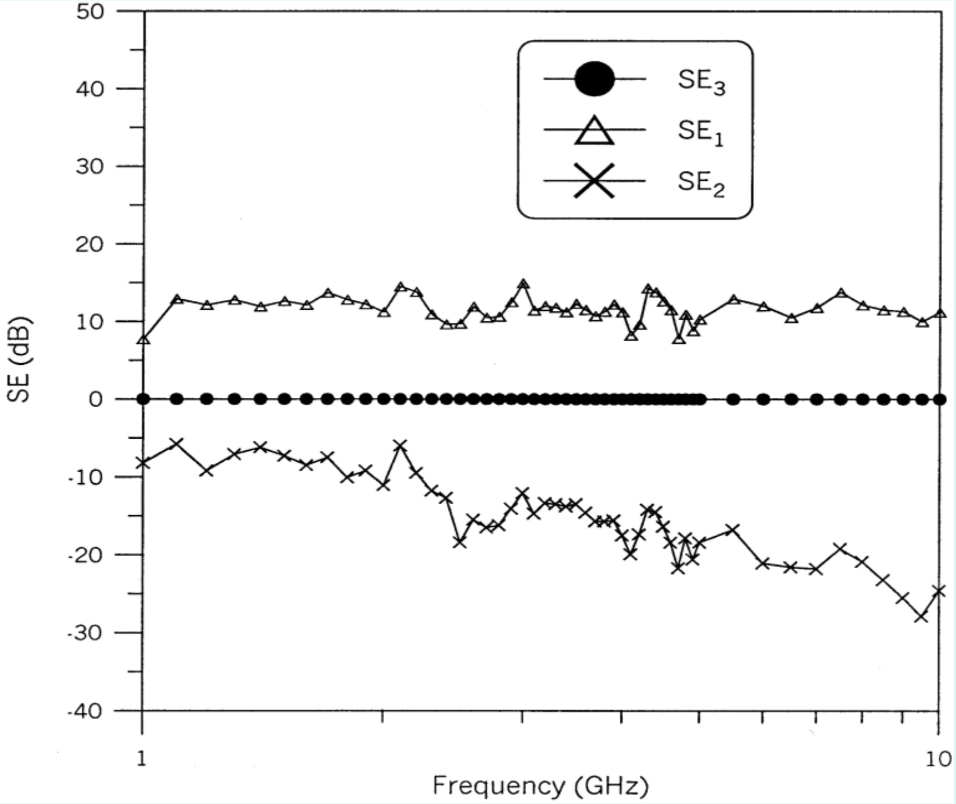
$$I_{ns} = \frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}}\frac{P^{i}_{rx,o,ns}}{P^{i}_{rx,i,ns}} \leq 0.1$$

A sufficient condition is:

$$SE_{fixt,ns} = -10\log\left(\frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}}\right) \geq 5 \text{ dB}$$

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

Results from models SE1, SE2, and SE3 with no sample in the aperture.




SE obtained from the three approaches with no sample in the aperture.

The outer chamber has dimensions of 2.76 m x 3.05 m x 4.57 m. The inner chamber has dimensions of 1.46 m x 1.17 m x 1.41 m with an aperture size of 0.25 m x 0.25 m

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

- The model in the standard is not supported by the theory

$$SE = 10\log\left(\frac{P^{o}_{rx,o,s}}{P^{o}_{rx,i,s}}\right) - 10\log\left(TFVF\right)$$

$$= 10\log\left(\frac{P^{o}_{rx,o,s}}{P^{o}_{rx,i,s}}\right) - 10\log\left(IL_{fixt,s}\right)$$

The model is used when the isolation with sample in the aperture is greater or equal than 10 dB

$$I_s = \frac{P^{o}_{rx,i,s}}{P^{o}_{rx,o,s}} \frac{P^{i}_{rx,o,s}}{P^{i}_{rx,i,s}} \leq 0.1$$

A sufficient condition is:

$$SE_{fixt,s} = -10\log\left(\frac{P^{o}_{rx,i,s}}{P^{o}_{rx,o,s}}\right) \geq 5 \text{ dB}$$

When the condition on the isolation is not met, the procedure for SE3 can be used. Moreover, the max value is considered.

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

Model SE3 can be simplified and proposed to improve the standard in all cases.

$$SE_{imp} = 10\log\left(\frac{P^o_{rx,o,s}}{P^o_{rx,i,s}}\right) + 10\log\left(\frac{A_a/4}{A_e} IL_{fixt,s}\right)$$

$$= 10\log\left(\frac{P^o_{rx,o,s}}{P^o_{rx,i,s}}\right) + 10\log\left(TFVF1\right)$$

- The model is valid when the isolations with or with no sample in the aperture are greater or equal than 10 dB.

For nonmarginal shields

$$I_s = \frac{P^o_{rx,i,s}}{P^o_{rx,o,s}} \frac{P^i_{rx,o,s}}{P^i_{rx,i,s}} \le 0.1$$

For marginal shields

$$I_{ns} = \frac{P^o_{rx,i,ns}}{P^o_{rx,o,ns}} \frac{P^i_{rx,o,ns}}{P^i_{rx,i,ns}} \le 0.1$$

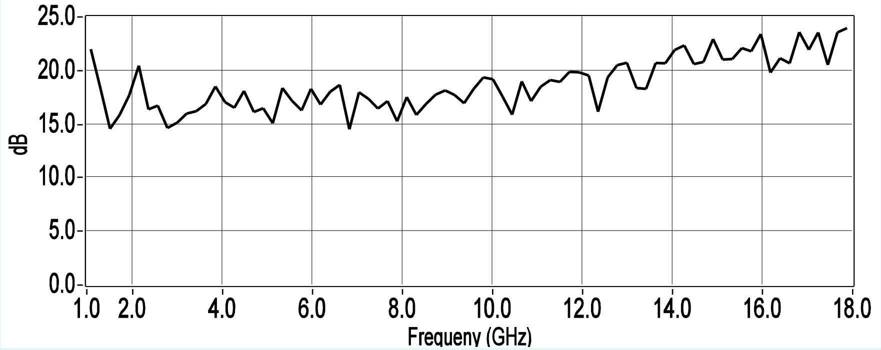
Sufficient conditions are respectively:

$$SE_{fixt,s} \ge 5 \text{ dB}$$

$$SE_{fixt,ns} \ge 5 \text{ dB}$$

# EXAMPLES OF SHIELDING EFFECTIVENES MEASUREMENTS

- The chamber is a cubic with the side of 2 m.
- The fixture has a cubic form where the side is 50 cm. The size of the aperture is 10 cm x 10 cm.




Chamber isolation $I_{ns}$ achieved in the measurement configuration used for the measurements of $R_c$.

$$I_{ns} = \frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}} \frac{P^{i}_{rx,o,ns}}{P^{i}_{rx,i,ns}} \leq 0.1$$

# EXAMPLES OF SHIELDING EFFECTIVENES MEASUREMENTS

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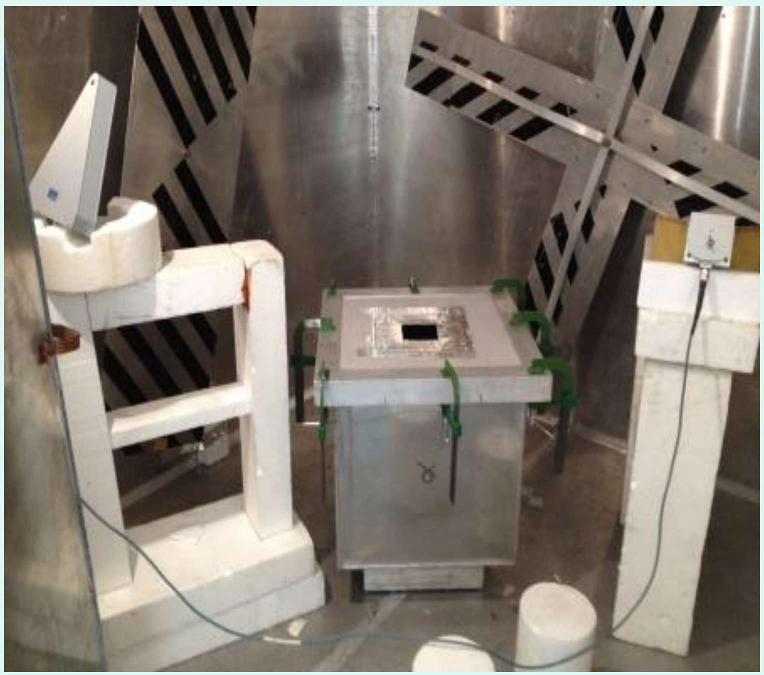
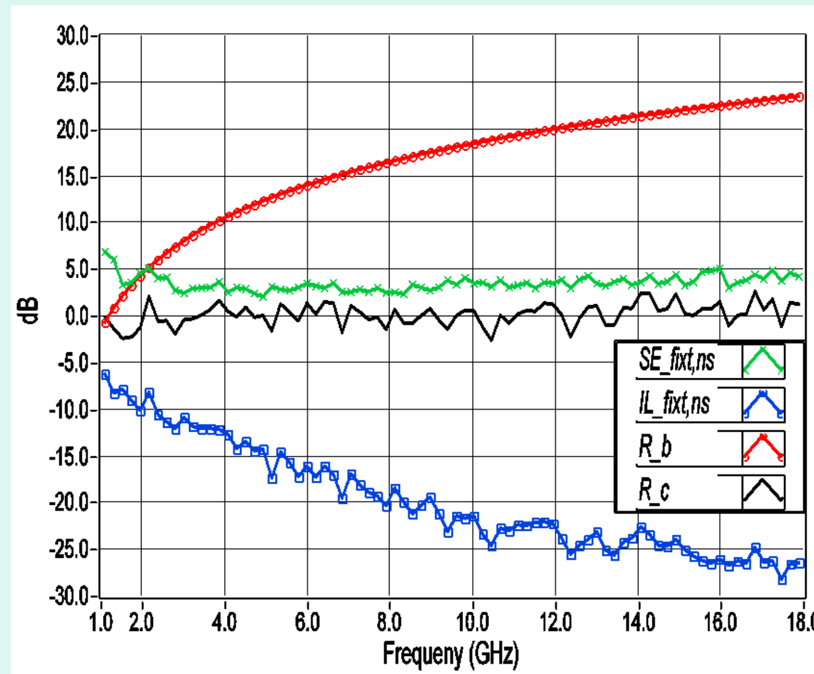


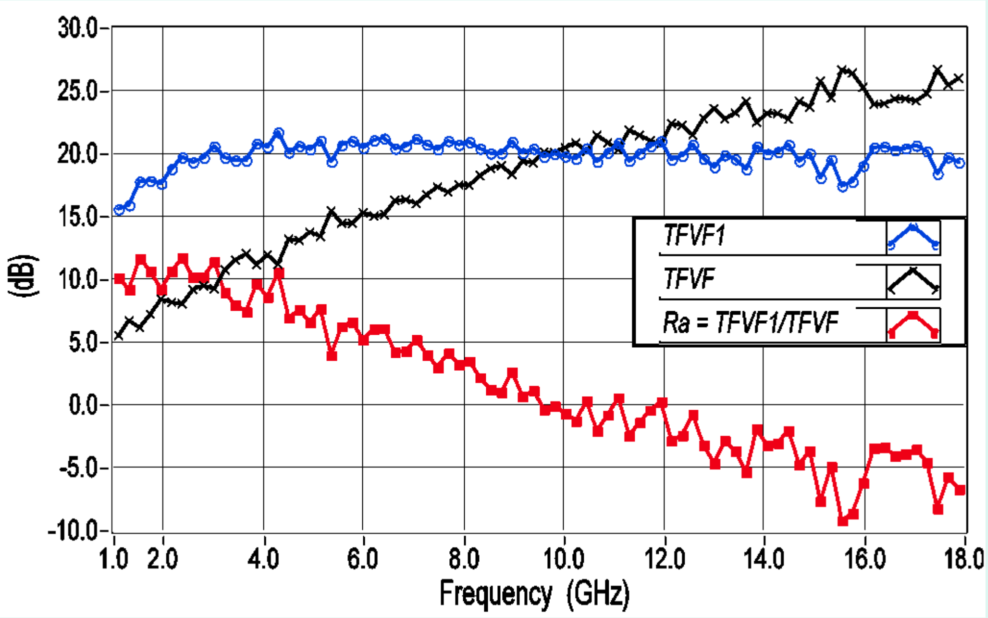



The red-colored and circle-marked trace represents the ratio $R_b = (A_a/4)/A_e$; the blue-colored and square marked trace represents $IL_{fixt,ns}$; the green-colored and cross-marked trace represents $SE_{fixt,ns}$; the black-colored and unmarked trace represents $R_c = SEap$.

$$R_b = 10\log\left(\frac{TFVF1}{TFVF2}\right) = 10\log\left[\frac{A_a/4}{A_e}\right] \qquad R_c = SE_{ap} = 10\log\left(\frac{A_a/4}{A_e}\frac{P^o_{rx,o,ns}}{P^o_{rx,i,ns}} IL_{fixt,ns}\right)$$

EXAMPLES OF SHIELDING EFFECTIVENES MEASUREMENTS

The fixture has a cubic form where the side is 50 cm. The sizes of the aperture are 10 cm x 10 cm.




$$R_a = 10\log\left(\frac{TFVF1}{TFVF}\right)$$

$$= 10\log\left[\frac{A_a/4}{A_e}\left(IL_{fixt,s}\right)^2\right]$$

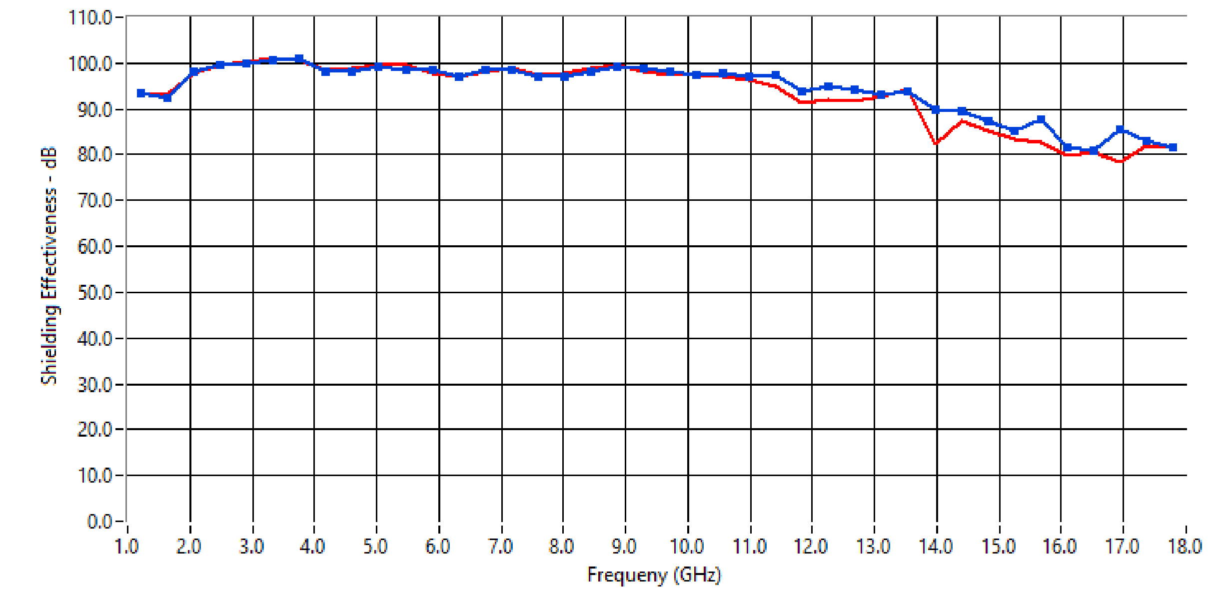
Fig. 5. The blu-colored and circle-marked trace is *TFVF*1. The black-colored and cross-marked trace is *TFVF*. The red-colored and square-marked trace is $R_a$ = *TFVF1*/ *TFVF*. The trace concerns a configuration for the SE measurement of Gaskets.

# FIXTURE

(a) Fixture used for measurements.

Details on the aluminium frame and the clamps.

# EXAMPLES OF SHIELDING EFFECTIVENES MEASUREMENTS




Shielding effectiveness of the material: the blue and square-marked trace is the SE of the fixture with aluminium slab in the aperture; the red and unmarked trace concerns the SE of the matching load.

Both traces represent the MDR. Measurements were made using an IF = 2 Hz (PNA, Agilent E8363B – 10 MHz to 40 GHz).

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

All models use four antennas. Two antennas are placed inside the fixture (smaller chamber for nested reverberation chambers sistems NRCSs)

Is it possible to reduce the number of antennas?

1. A single antenna can be used in the fixture when gaskets or any flat material having a not much high absorbing and considerable reflectivity at least on the side where the field impinges the field by the fixture. This case generally includes complex printed circuit boards (PCBs) and complex printed circuit boards assembly (PCBAs) etc..
2. Measurements of SE of gaskets and materials can be made by using only two antennas when the Q of the two chambers remain practically constant with no sample and with sample in the aperture. We give a simply and usable condition on the applicability of the simplest model to measure SE. The model is denoted by SE4.

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

For samples having a not much high absorbing and considerable reflectivity at least on the side where the field impinges by the fixture, a single antenna can be used inside the fixture.

$$SE = 10\log\left(\frac{P^{o}_{rx,o,s}}{P^{o}_{rx,i,s}}\right) + 10\log\left(\frac{A_a/4}{A_e}\right) + 10\log\left(IL_{fixt,pec}\right)$$

$$= 10\log\left(\frac{IL_{o,s}}{IL_{oi,s}}\right) + 10\log\left(\frac{A_a/4}{A_e}\right) + 10\log\left(IL_{fixt,pec}\right)$$

$$IL_{fixt,a,ns} = \frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}}\frac{A_e}{A_{a,a}/4} = \frac{1}{SE_{fixt,a,ns}}\frac{A_e}{A_{a,a}/4}$$

$$ACS_{fixt,a,ns} = \frac{1}{2}\frac{\lambda^2}{4\pi}\frac{1}{IL_{fixt,a,ns}}$$

$$I_{ns} = \frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}}\frac{P^{i}_{rx,o,ns}}{P^{i}_{rx,i,ns}} \le 0.1$$ A sufficient condition is $$SE_{fixt,ns} \ge 5\ \text{dB}$$

*ILfixt,pec* is the IL of the fixture when the aperture is covered by a metallic slab. It is achieved by *ILfixt,a,ns* when a minimum auxiliary large aperture is used. The initial large aperture could covered by an aluminium tape to meet the necessary isolation.

$$IL_{fixt,pec} = \frac{1}{2}\frac{\lambda^2}{4\pi}\frac{1}{ACS_{fixt,a,ns} - A_{a,a}/4}$$

← Novelty element

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

When the following holds

$$P^o_{rx,o,ns} = P^o_{rx,o,s} \Rightarrow IL_{o,ns} = IL_{o,s}$$

and we can write

Note that this term is not the SEfixt in this case.

$$SE = 10\log\left(\frac{P^o_{rx,i,ns}}{P^o_{rx,i,s}}\right) + 10\log\left(\frac{IL_{fixt,pec}}{IL_{fixt,a,ns}}\right)$$

$$= 10\log\left(\frac{IL_{o,i,ns}}{IL_{o,i,s}}\right) + 10\log\left(\frac{IL_{fixt,pec}}{IL_{fixt,a,ns}}\right)$$

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

The simplest model to measure *SE* is denoted by $SE_4$.

$$SE_4 = 10\log\left(\frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,i,s}}\right) = 10\log\left(\frac{IL_{o,i,ns}}{IL_{o,i,s}}\right)$$

We give a new, simple, and usable condition for the applicability of $SE_4$.

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

$$\frac{IL_{fixt,ns}}{IL_{fixt,pec}} = 1 - \frac{A_a/4}{ACS_{fixt,ns}} = 1 - \frac{1}{SE_{fixt,ns}}$$

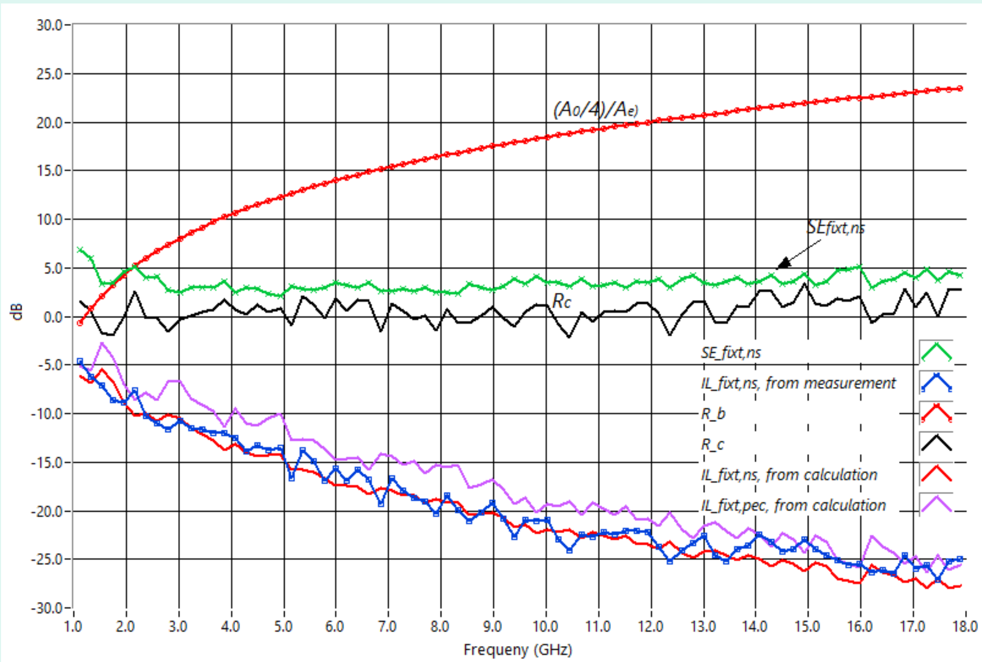
The simplest model *SE4 can be applied under the condition*

$$SE_{fixt,ns} \geq 4 = 6dB \Rightarrow \frac{IL_{fixt,ns}}{IL_{fixt,pec}} \geq 0.75 = -1.2dB$$

⇐ Novelty element

# EXAMPLES OF SHIELDING EFFECTIVENES MEASUREMENTS

The chamber is a cubic with the side of 2 m.
The fixture has a cubic form where the side is 50 cm. The sizes of the aperture are 10 cm x 10 cm.




The second last and the last trace are the *ILfixt,ns* and *ILfixt,pec* are calculated by formulas shown above.

Note that the condition SEfixt,ns ≥ 6 dB is not met!

$$IL_{fixt,a,ns} = \frac{P^{o}_{rx,i,ns}}{P^{o}_{rx,o,ns}} \frac{A_e}{A_{a,a}/4} = \frac{1}{SE_{fixt,a,ns}} \frac{A_e}{A_{a,a}/4}$$

$$IL_{fixt,pec} = \frac{1}{2}\frac{\lambda^2}{4\pi}\frac{1}{ACS_{fixt,a,ns} - A_{a,a}/4}$$

# USE OF REVERBERATION CHAMBERS FOR SHIELDING EFFECTIVENES MEASUREMENTS

We can achieve the difference in MDR between a given method and the method $SE_4$ by the difference between the $SE_{fixt,ns}$ concerning the given method and the $SE_{fixt,ns}$ concerning $SE_4$. If the difference is positive, we have a reduction in MDR for $SE_4$, whereas if the difference is negative, we have an increase in MDR for $SE_4$. We can write:

$$\text{Diff-MDR}_{dB} = SE_{fixt,ns,SE_4,dB} - SE_{fixt,ns,dB}$$

where Diff-MDR represents the difference in MDR between a given method and SE4, whereas the subscript dB means that we are considering the concerning value in dB.

We stress that the MDR can be increased by a reduction of the volume of the greater chamber.

Note that by using chambers with volumes and apertures appropriately reduced, the measurement frequency range could be extended to some tens of GHz including frequencies for 5G communication system, where the simplest model is the best to be used.

CONCLUSIONS

Current standard on *SE* measurements of gaskets and materials can certainly be improved. Different way are practicable to improve it:

1. By the simplification of the model $SE_3$, so that it becomes similar (but not equal) to that in the standard.
2. For gaskets and any material having a not much high absorbing and considerable reflectivity, measurement setup can be simplified by using a single antenna in the fixture; no limitation on the sizes of the sample with respect to a full side of the fixture.
3. By using a simply condition on the *SE* of the fixture with no sample in the aperture, the simplest model for *SE* measurements ($SE_4$) of gaskets and materials can be used. The sizes of the samples are limited by the size of the large aperture.
4. About the previous point 3., we have a possible but reasonable reduction of the MDR.

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THANK YOU VERY MUCH
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