Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2019) 27: 3088 – 3097
© TÜBİTAK
doi:10.3906/elk-1902-68

Effect of orientation of RF sources maintained within the enclosures on electrical shielding effectiveness performance

İbrahim Bahadır BAŞYİĞİT[1,*], **Abdullah GENÇ**[2], **Selçuk HELHEL**[3]

[1]Department of Electrical and Electronics Engineering, Faculty of Technology, Isparta University of Applied Science, Isparta, Turkey

[2]Department of Mechatronics Engineering, Faculty of Technology, Isparta University of Applied Science, Isparta, Turkey

[3]Department of Electrical and Electronics Engineering, Faculty of Engineering, Akdeniz University, Antalya, Turkey

Received: 09.02.2019 • **Accepted/Published Online:** 05.05.2019 • **Final Version:** 26.07.2019

Abstract: The effect of single aperture metallic enclosures on electrical shielding effectiveness (ESE) has been investigated. Simulations and measurements have been obtained for comparison. The effects of orientation of transmitting antenna (source orientation) with respect to aperture length have been studied at 2.60–9 GHz as a novelty, and this gives details of IC RF source orientation in an enclosure. In the case of square apertures on an enclosure, a higher ESE value is obtained with respect to a rectangular aperture. As a case study, when the aperture width of the enclosure is decreased from 75 to 18.75 mm, the frequency bandwidth of ESE with vertical orientation becomes higher. In other words, while the area of the aperture is fixed, decreasing aperture width increases ESE for vertical orientation. In the next case, ESE with vertical orientation is better at 34.37%, 71.87%, and 99.98% of the full frequency range than the horizontal one while the ratio of aperture length/width is 1, 4, and 16, respectively. It has been found that the vertical orientation of sources with respect to aperture-length orientation is predominant for the horizontal orientation of it on ESE performance.

Key words: Shielding effectiveness, shielding enclosure, electromagnetic compatibility, orientation of RF sources

1. Introduction

Electromagnetic interference (EMI) is one of those major problems for electronics itself and electronic infrastructures. This phenomenon happens either as immunity or susceptibility where sensitive electronics may sustain damage in an electrical environment [1]. The fundamental solutions of this problem are designed considering the quality of electronic components as well as their distribution on the board. I/O connections, grounding, and chases are also critical issues. Shielding is one of the major effective methods to decrease the emissions and advance the electronic equipment immunity. The shielding effectiveness (SE) is generally used to calculate the shielding effect [2, 3]. Enclosures and their peripherals normally have apertures for maintenance, cooling, and ventilation. Those apertures are against case shielding and at different pattern shapes and sizes for control panels, heat dissipation airing, and cable penetration they result in decreased shielding performance due to electromagnetic energy leakage [4, 5].

The main conflict during the design steps of electronics and electronic systems is that the EMI perspective requires 100% shielded enclosures, but the ventilation and cooling perspective requires totally open enclosures.

*Correspondence: bahadirbasyigit@isparta.edu.tr

There should thus be an optimum aperture size and shape that maintains the above requirements in addition to cabling and grounding. For making decisions about optimum aperture size and shape, one needs to illuminate the shielding properties of enclosures. There are various numerical studies [6–11] and analytical formulations [12, 15] to compute the shielding effectiveness of enclosures with rectangular apertures. In this case, analytical calculations are much faster than numerical methods. We have investigated SE parameters before [16]. There are also some studies that calculated the electrical shielding effectiveness (ESE) of an enclosure with apertures using COMSOL simulation [17].

Between 2 GHz and 9 GHz, emerging technologies will commercially be ready soon. The wireless USB is used in 3.1–10.6 GHz. A body area network (BAN) is operated in 7.25–8.5 GHz. Some electron paramagnetic resonance spectroscopy is used at nearly 9 GHz. At 2.3 GHz, 3.4 GHz, and 5.8 GHz, wireless data and multimedia radio are running. Ultrasonic imaging of high ultrasound waves operates up to 4 GHz. Some IEEE standards and WIMAX applications operate between 2 GHz and 11 GHz. The ultrawide-band (UWB) technology of personal area networks (PANs) can be used with the IEEE 802.15.3a standard [18]. Indoor applications in UWB [19–21] such as PC units involve low emission levels. Digital picture printing processes, digital camcorder data transfer, wireless monitors, etc. use UWB at high data rates for mobile multimedia applications [22]. An increased usage of UWB frequencies in a wide range of commercial and military applications forced EMC test authorities to extend the CISPR-16 EMC test range up to 6 GHz, and it can normally be expected that these test limits will be extended to frequencies including X-band. This increase in UWB electronics motivated us to make measurements of ESE conducted from 2.6 GHz to 9 GHz and to compare the results with simulations. During this study, most of the studies in the literature mainly focused on SE up to 2 GHz have been ignored.

In this study, measurements were conducted for different aperture sizes and dimensions, and Comsol 4.4 has been used for simulation. Number of mesh cells was 952,300 and mesh shape was tetrahedral in the simulations. The maximum mesh length is $\lambda_{min}/15$ and the computing time is between 31 min and 33 min. It is important to say that all parameters have been simulated with a PC using a 128 GB SSD and Intel Core i5 2.40 GHz processor with 8 GB RAM. Comsol performed automatic selection for boundary conditions for producing better performance.

The main purpose of this study is demonstrating the effect of source orientation on electrical shielding effectiveness under certain conditions. Vertical orientation and horizontal orientation of RF sources have been selected because of their simplicity. For this aim, as a first step, verification of measurement results with simulation in order to see the effect of aperture length/width ratio on ESE has been performed. Secondly, we compare the results of vertical and horizontal orientations in terms of which region is better for ESE performance by means of measurement results at 2.6 GHz to 9.0 GHz as a novelty. A meaningful contribution to the main problem of system designers has also been aimed during the study. It should be noted that no specific case design has been offered in the study, since the aim of this paper is understanding the relation between orientation of RF sources installed in a case with the dimensions of an aperture.

The paper is organized as follows. We give information about the details of the measurement and simulation in Section 2. Section 3 includes the results of simulations, measurements, and performance analysis. Section 4 gives the conclusion and future work.

2. Test and measurement setup

SE measurements have been conducted in an anechoic chamber having dimensions of 4 m × 4 m × 8 m according to the relevant IEEE standard [23]. A horn antenna operating at 1–18 GHz as a transmitting antenna and flange pin terminal with N-type connector (Product ID: PE4355; DC to 18 GHz) as a receiving antenna (probe) have been used. Measurement setup details are shown in Figure 1. A low-loss broadband RF coaxial cable operating between DC and 18 GHz has been used. Three different 4 μm-thick metallic enclosures having different apertures on them were selected as metallic cases under test (μCUT) for ESE measurements. The flange pin is through the center of the bottom surface of the enclosure. Details of those enclosures are given in the Table. Enclosure length, width, and depth is a, b, and d, respectively. Aperture length is l and width is w.

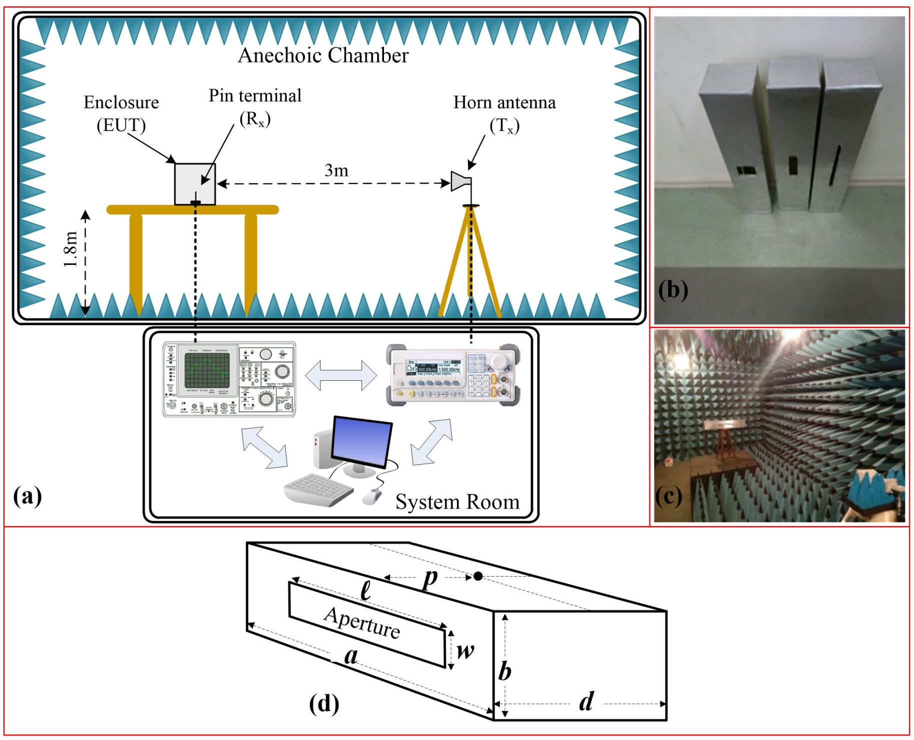

Figure 1. Test and measurement setup: a- block diagram of test set-up; b- enclosures having different aperture sizes as detailed in the Table; c- anechoic chamber; d- dimensions of enclosure with aperture.

The ESE performances of μCUTs as detailed in the Table were measured first and simulated by means of Comsol Multiphysics software as a second step to verify results. Measurements were repeated for different aperture sizes and both vertical and horizontal positions of the transmitting antenna with respect to longitudinal aperture orientation. Measurements were carried out between 2.6 and 9 GHz with 10-MHz measurement intervals. Each frequency measurement was repeated 20 times to reduce measurement errors using mean values. During conducted measurements, procedures of the IEEE 299-2006 standard method for measuring the effectiveness of electromagnetic shielding enclosures were used [23].

Table. Enclosure dimension details for conducted measurements.

Case no.	a (mm)	b (mm)	d (mm)	l (mm)	w (mm)
Case 1	800	160	160	75	75
Case 2	800	160	160	150	37.5
Case 3	800	160	160	300	18.75

3. Results and performance analysis

ESE can be calculated as in Eq. (1). The case in which the probe is in the metallic box is E_a, and that where the probe is not in the metallic box (reference measurement) is E_p. Since enclosures have great potential to behave like resonators, one needs to look the close resonance frequencies in analysis. For this goal, Eq. (2) is the mathematical definition of the resonance frequency at TE mode of any enclosures having dimensions of a, b, and d, and this equation basically tells us that resonance frequency gets smaller with increased enclosure size [24].

$$ESE = 10log\frac{E_a}{E_p} \qquad [dB] \qquad (1)$$

$$(f_{resonance})^{TE}_{mnp} = \frac{1}{2\pi\sqrt{\mu e}}\sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2 + (\frac{p\pi}{d})^2} \qquad [Hz] \qquad (2)$$

Here m, n, p = *0,1,2,3, ..*, except $m = n \neq$ *0.* Measurement and simulation results with horizontal polarization nearly overlap each other as seen in Figure 2, Figure 3, and Figure 4. It is important to note that measurement results are averagely smoothed for quick analysis and predicting trends in ESE.

In Figure 2, at resonance frequencies, ESE performance is dramatically negative and performance is at about the level of –20 dB (at most –30 dB), and this phenomenon can be called a resonating one that leaks a high level of undesired electric fields out of an enclosure. These resonance frequencies are periodical by ∼2-GHz intervals. ESE performance is quite good as it reaches the level of ∼80 dB. In simulation results, the number of mesh cells is 934,100 and mesh shape is tetrahedral. For the minimum wavelength, discretization has conducted taking into account more than 15 elements. Calculation elapsed times are nearly 32 min. As seen in Figure 2, simulation and measurement results follow each other in a good manner.

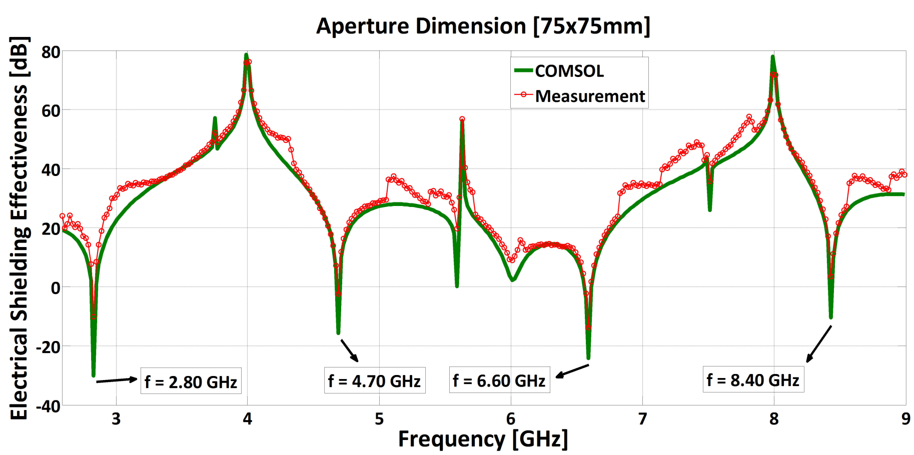

Figure 2. ESE results of enclosure with aperture for case 1.

In Figure 3, at the resonance frequencies mentioned before, ESE has its worst performance level of –18 dB and the average ESE performance is about –10 dB. These levels are roughly 10 dB better than the results in Figure 2. In a similar manner, the best ESE performance level is about ∼80 dB at 8 GHz. Figure 2 shows that ESE performance increases by 7 dB at every 1-GHz interval that ESE reaches from 0 dB to 40 dB throughout the frequency band, except resonance frequencies. For the minimum wavelength, discretization has been conducted taking into account more than 15 elements. Calculation elapsed times were nearly 36 min. As seen from Figure 3, simulation and measurement results are tracking each other.

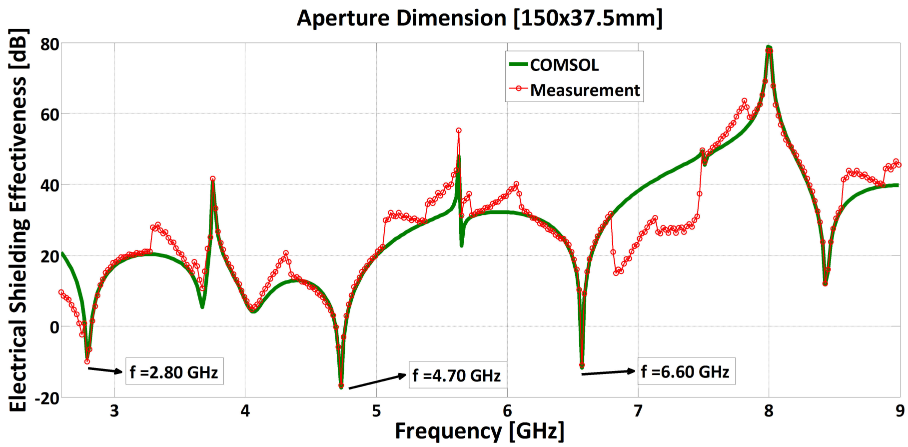

Figure 3. ESE results of enclosure with aperture for case 2.

Figure 4 shows that the ESE performance of the enclosure is better than the previous two enclosures on average. It is about 20 dB at 2.7 GHz and reaches 40 dB by 2 dB increases in every 1-GHz interval. There are only two resonance frequencies having negative performances in very narrow bands that get worse up to about –20 dB. In simulation results, the number of mesh cells is 944,200 and the mesh shape is tetrahedral. For the minimum wavelength, discretization has been conducted taking into account more than 15 elements. Calculation elapsed times were nearly 33 min. As seen from Figure 4, simulation and measurement results are tracking each other. Normally, we expect to observe similar responses for both vertical and horizontal orientations, but there is an inconsistency of about 33%. This can be explained due to coupling between the transmitting antenna and metallic enclosure. For the vertical orientation, the area of the metallic surface of an enclosure near the transmitting antenna is smaller than in the case of horizontal orientation (see case structure in Figure 1).

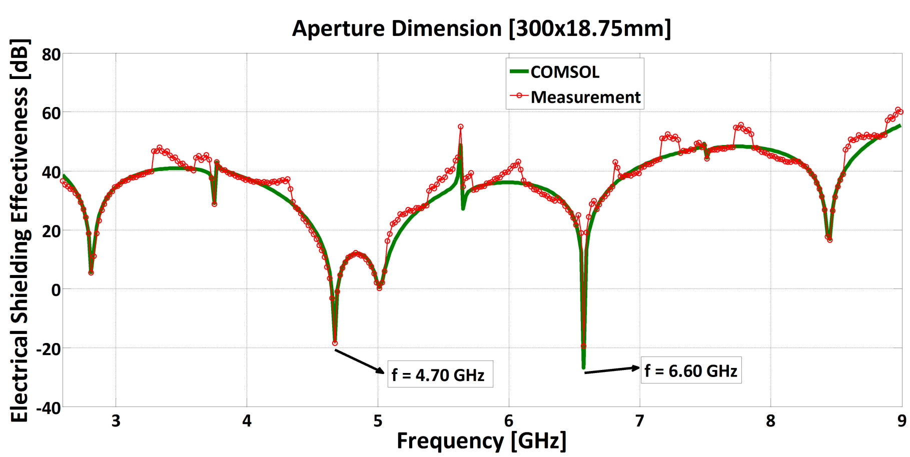

Figure 4. ESE results of enclosure with aperture for case 3.

Figure 5, Figure 6, and Figure 7 have been plotted in order to make comparisons of the effects of aperture dimensions as well as source orientation with respect to longitudinal aperture orientation. Those figures are composed of three parts. The first and upper plot is for ESE results of both vertically and horizontally oriented sources, the second and middle plot is a selection plot that mainly demonstrates logical “1” and “0”, and the last plot is the lower one demonstrating the differences between those two. In Figure 5, Figure 6, and Figure 7, red lines refer to horizontally maintained/oriented RF sources in the enclosures and blue lines refer to vertically maintained ones. In the middle of each figure, blue straight lines show the usage of vertical orientation of RF sources and red straight lines show the usage of horizontal orientation of RF sources in that frequency band for its own aperture scenario.

A square-type aperture has been chosen as an initial step, and Figure 5 shows ESE performance in both vertical and horizontal orientations/maintaining of RF sources. Since one expects to see a similar performance in both orientations, we dramatically obtain different responses. This may be due to the receiver orientation; that is another issue and will be investigated in the future. For intervals of 2.6–3.6 GHz, 4.4–5.0 GHz, and 5.2–6.8 GHz, plots offer horizontal orientation of RF sources rather than vertical ones for better ESE performance, and one may offer the opposite for frequency intervals of 3.6–4.4 GHz and 6.8–9 GHz. ESE performance is negative at resonance frequencies and one needs to consider this point during design steps. Frequency shifts observed at first and third resonance frequencies are assumed as measurement error.

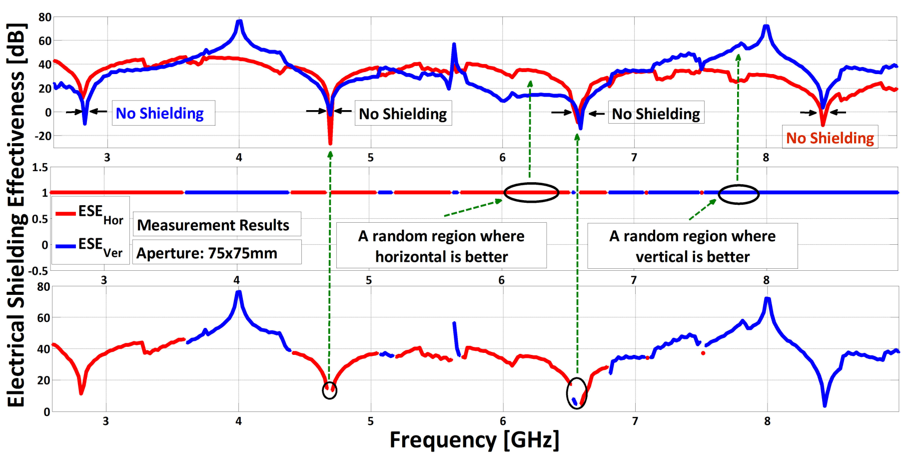

Figure 5. Comparison measurement results of vertical and horizontal orientation for case 1.

An aperture having the same total area but different dimensions (length/width ratio is 4) was chosen as a second scenario, and Figure 6 shows the ESE performance in both vertical and horizontal orientations/maintaining of RF sources. For intervals of 3.2–4.8 GHz and 7.3–7.5 GHz, horizontal orientation of RF sources is better than vertical for obtaining better ESE performance, and for the frequency intervals of 2.6–3.2 GHz, 4.8–7.3 GHz, and 7.5–9.0 GHz the opposite is true. ESE performance is negative at resonance frequencies, as in the first scenario. In comparison with the square-type aperture, a frequency band that is offered for vertical orientation is wider in this scenario. In general, this plot offers the usage of vertical orientation of RF sources rather than horizontal for obtaining better ESE performance, which is about 72%.

Figure 7 shows the response plot for the scenario of an aperture where aperture length-width ratio is 16. Vertical orientation of RF sources has comparably better performance on the whole frequency band. While the aperture length-width ratio is increasing from 1 to 16 (the aperture width of the enclosure is decreased from 75 mm to 18.75 mm) according to scenario mentioned above, vertical orientation yields better ESE values in the frequency range of 2.2 to 6.4 GHz. In other words, while the area of aperture is fixed (5625 mm^2), decreasing the aperture width results in better ESE performance for vertical orientation. We may explain these

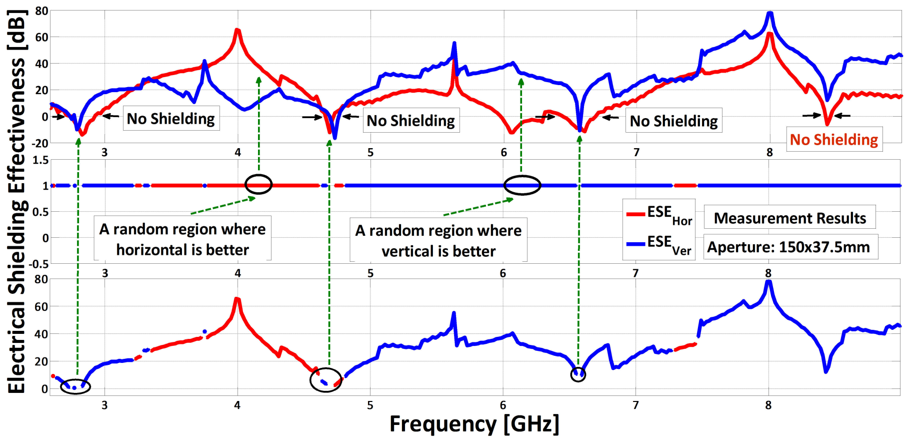

Figure 6. Comparison measurement results of vertical and horizontal orientation for case 2.

phenomena by the fact that the perpendicular polarization of the electric field is vertical to the traveling plane wave. If the transmitting antenna and aperture width are in the same orientation, leaked amplitude must be expected as maximum. Frequency shifts observed at the second and third resonance frequencies are assumed as measurement error.

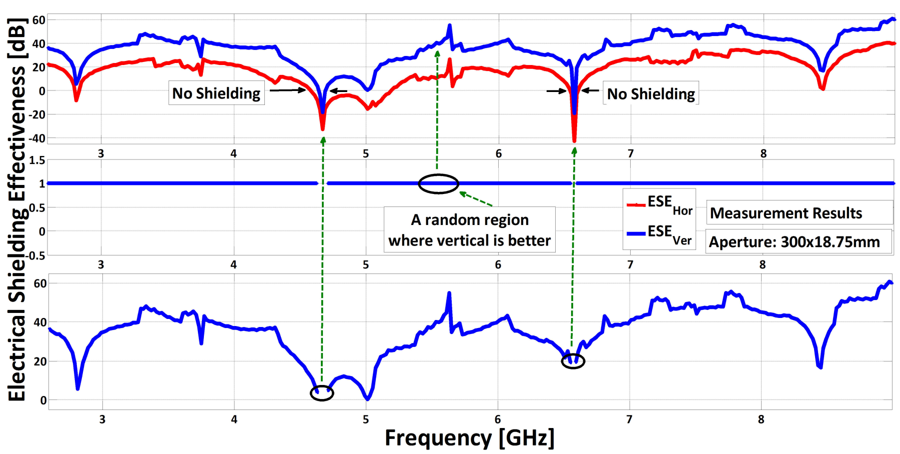

Figure 7. Comparison measurement results of vertical and horizontal orientation for case 3.

In Figure 8, ESE measurements have been compared where the first, second, and third subfigures are for scenarios 1, 2, and 3, respectively. With the help these results, there is no need to pay attention to aperture geometry/size for the intervals of 6.81–7.27 GHz and 7.47–9 GHz. For these frequency ranges, vertical orientation is better than horizontal regardless of aperture geometry/size. Outside of these frequency ranges, it is necessary to pay attention to aperture geometry/size to choose one of the linear polarizations, as seen in Figure 5, Figure 6, and Figure 7).

4. Conclusion

Obtaining negative ESE performance after integration of internal electronics in an enclosure is a harmful situation that needs to be overcome. Otherwise, the offered design behaves in an uncontrolled manner, emitting sources that result in the breaking of information security (unintended information leakage). As obtained from

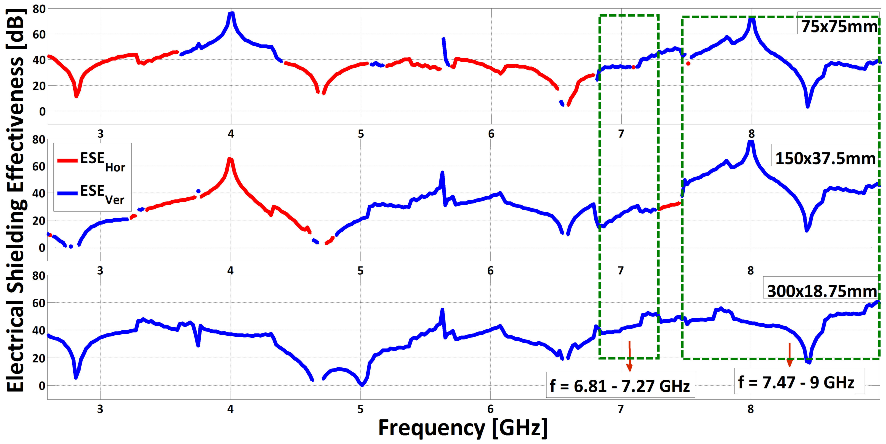

Figure 8. Comparison of all enclosures with linear polarizations.

the measurements verified by simulations, a designer may need to change the maintained position of electronics in an enclosure with respect to aperture dimension, operating frequency of electronics, dimensions of enclosures, or aperture length/width ratio. Also, if the transmitting antenna and aperture width are in the same orientation, leaked amplitude is observed.

It has been found that vertical orientation of sources with respect to aperture-length orientation is predominant to horizontal orientation for ESE performance. For the frequency ranges of 6.81–7.27 GHz and 7.47–9.0 GHz, vertically oriented/maintained RF sources are predominant to horizontal ones for performance of ESE in this scenario. Finally, electronic system designers should consider the source (UCs and RFs) maintaining the orientation within the enclosures and systems in addition to their operating frequencies.

As a future work, the effect of intrasystem and intersystem orientations of RF sources will be proposed for increasing ESE performance.

Acknowledgments

This work was supported by the Department of Scientific Research Projects of Süleyman Demirel University as “Investigation the effect on total electromagnetic emission distribution of metallic enclosure topology”/“Metalik kutulama topolojisinin toplam elektromanyetik emisyon dağılımına etkisinin incelenmesi” [Project Number: 4384-D2-15]. The authors thank the Directorate of Industrial and Medical Applications Microwave Research Center (EMUMAM), Akdeniz University, for allowing them to use the EMC Pre-Compliance Test Laboratory facilities granted by the State Planning Organization (Project Number: 2007K120530-DPT). As the contributions of the authors to the study, S.H. gave the idea, İ.B.B. and A.G. did the experiments, and İ.B.B. interpreted the results and wrote the paper.

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