High-performance magnetic shielding solution for extremely low frequency (ELF) sources

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Abstract: Some particular aspects related to open shields with high performance are presented. The magnetic flux density targets related to the protection of sensitive devices are quite low, <0.2 µT. The problem to reach high magnetic field attenuation is more complicated by the fact that open shields have to be adopted instead of closed solutions. After some general considerations about open shields two practical examples are presented and discussed.

1 Introduction

Often the need of very low environmental magnetic flux density, as in the case of laboratories where high sensitive devices are installed (e.g. electronic microscopes), requires a suitable design of magnetic shielding systems able to reach high attenuation factors. In particular, when the laboratories are close to ELF sources (usually 50 or 60 Hz) the magnetic shield has to provide a global field reduction from some µT up to 0.1 or 0.2 µT [1].

Besides the restriction on magnetic field close to sensitive devices, there are in several country and especially in Europe some binding limits also for population aimed to prevent possible long-term effects [2]. A recent example is the restriction to magnetic field at low frequency introduced in France since 2013. The 'Ministère de l'Ecologie du Dévelopement Durable et de l'Energie' has published indications regarding the maximum level of magnetic flux density in sensitive area as hospitals, maternity, nurseries, kindergartens, primary schools etc. Such value, expressed as an average over 24 h, is 0.4 µT. In order to satisfy this limit a distance of compliance ('bordure de zone de prudence') associated to 1 µT must be guaranteed for new plant installations as overhead and buried cable, substation etc.

Sometimes active and/or passive shields can work separately or together to better fit the mitigation requirements [3, 4]. Moreover, regarding passive solutions, the shield of the clean room and the shield of the different sources can be adopted at the same time in order to obtain higher magnetic attenuation.

This study analyses the case of open shields with high performance in terms of magnetic field attenuation. After some general considerations about open shield design, two actual cases are reported and discussed.

2 Open shield consideration

Dealing with power plants which are usually constituted by power transformers, connections and switch gearboxes, different passive shielding solutions can be adopted. Commonly, the shield can be localised close to the source inside the substation or close to the victims: devices or people [5]. In both cases, especially when the shield is installed in a building already built, the shield is not closed completely around the source or the victim but is an open shield that leaves free openings as windows or doors.

Usually open shields are fixed on the separation walls between sources and victims inside the substation or inside the room are to be protected. In both cases the shield present some flaps, of about 1 m, which provide a reduction of the edge effects. It is well known that both ferromagnetic and conductive shields are subject to edge effects that produce a local increase of the magnetic flux density.

The performance of a shield is usually expressed by the ratio between the unshielded and the shielded magnetic field. This coefficient is called shielding factor (SF) and in the case of closed room is usually considered as unique number, often expressed in dB. For open shield this is not possible, the SF is point wise function of the space which decay going far from the shield. Even if the shielding factor is very high close to the shield (higher than 100) a value of five times at some metre from the shield is very satisfactory.

The last important topics regarding open shields are related to the materials. Usually, ferromagnetic shields are suggested in the case of shield very close to the victim while a conductive solution is convenient when the shield is closer to the source. A combination of the two materials makes it possible to reach a good mix of the attenuation principles of the two materials and good performances close and far from the shield [6].

3 Application cases

Two actual applications are presented in Section 3. A quite high magnetic field attenuation is required in both cases, SF higher than 15 and up to 30. The shielding solution must be integrated in existing plants and buildings and a reduced impact to the operational activity in the two sites is required.

3.1 Case 1

The first case presented deals with the attenuation of magnetic fields generated by a big power transformer close to a hospital laboratory. The magnetic flux density measured on the wall of the laboratory close to the substation was around 100 µT when the transformer works at 80% of the full load. The presence of people and electronic devices inside the laboratory requires a SF of about 30 close to the wall (at about 50 cm from the shield) in order to reach the target of 3 µT for people and 3.78 µT (3 A/m) for electronic devices. The proposed solution is based on a local shielding system acting directly on the source and so installed inside the substation.

The shield is made of three layers using conductive and ferromagnetic material. The thickness of each layer is defined to get the required shielding factor and to minimise the weight. A self-supporting structure has been made in order to minimise the installation time: only 3 h. Consequently, very reduced out of service of the power transformer was required. Fig. 1 shows the shield of the transformer during the installation.

Fig. 1 *Local shield for the power transformer*

The simulated performance of the shield is reported in Fig. 2 where it is possible to see that in the protected area the value of 3 μT is guaranteed.

Finally, Fig. 3 reported the measured SF which reaches a value of 150 times close to the shield and 30 times at 50 cm from the shield, according the problem requirements.

3.2 Case 2

The second example refers to the shielding of magnetic fields generated by a complex power substation on a test area where sensitive electronic devices are installed. Such devices are employed in a semi-conductor industry for the wafer testing and very low electrical currents are measured (in the order of fem-to-amperes). External magnetic fields have to be low enough in order to not to disturb the current measurements.

Level of 0.2–0.3 μT is usually required in the environment where the testing machines are placed.

Fig. 4 shows the layout of the power substation which is placed below the area where a new testing laboratory has to be installed (see red line in Fig. 4). The substation is composed by eight power

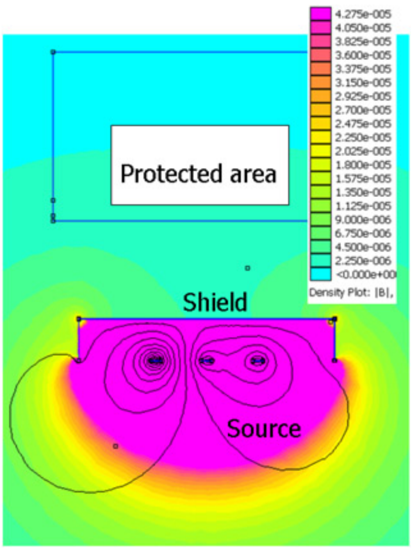

Fig. 2 *Simulation of the magnetic flux density distribution in the presence of the shield*

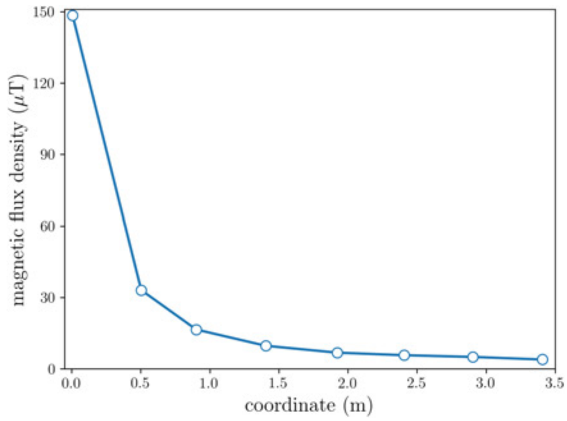

Fig. 3 *Magnetic field attenuation at the quote of 1 m from the ground for different distance from the shield*

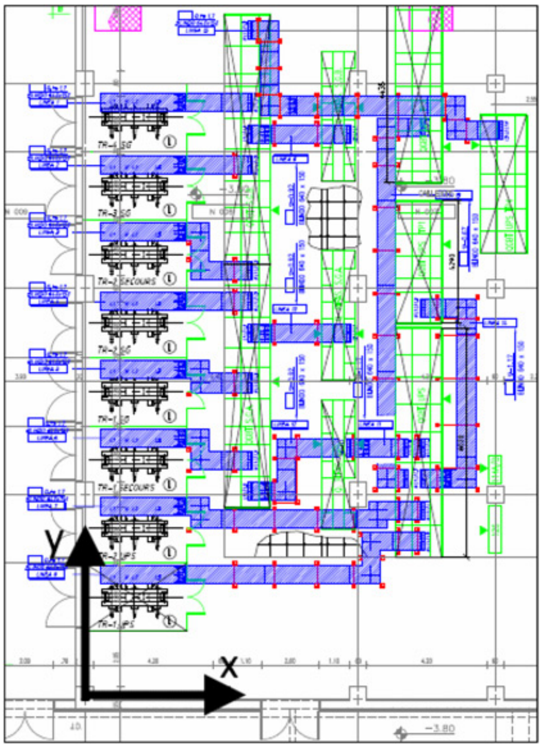

Fig. 4 *Layout of power substation and the indication of the above testing area*

transformers of 2500 kVA each and the connections among the transformers and the low voltage switch gearboxes are obtained by busbar systems (blue drawings).

Some preliminary measurements show a magnetic pollution in the testing close to 2–3 μT. Such value is quite constant because the substation works 24 h a day at constant load. A shielding factor of at least 10 is required. Before starting with the design of the shield the complete model of the substation has to be created. The model is made by a commercial software [7], takes into account the different sources and the layout of the substation (Fig. 5). The simulation of the magnetic flux density at the ground level of the testing area is reported in Fig. 6. According to the measurement, the maximum value calculated is equal to 3 μT. The chosen shielding shape is presented in Fig. 7 where only a portion of the area above the substation is shielded (blue area). The shielding is composed by multilayer plates made of conductive and ferromagnetic materials. The shield can also be observed in Fig. 8 where it is modelled using an integral formulation [8, 9].

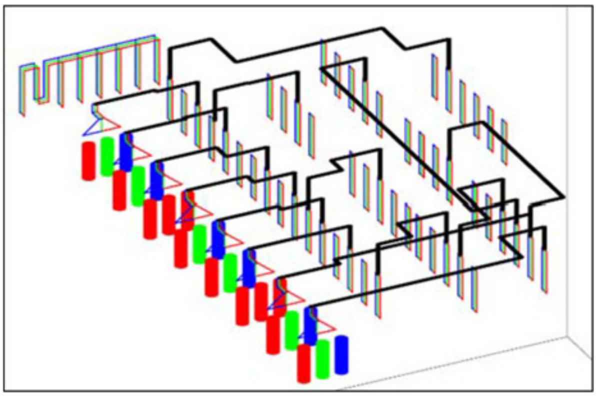

Fig. 5 *3D Model of the power substation: transformers and power lines*

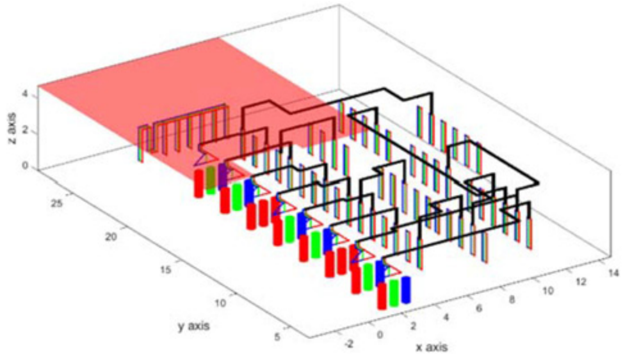

Fig. 8 *3D Model of the substation in presence of the shield*

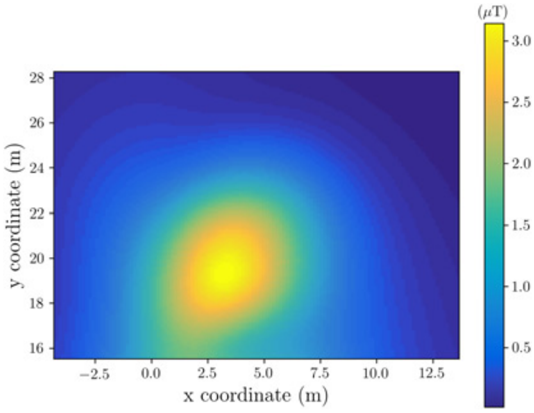

Fig. 6 *Simulated magnetic flux density distribution in the testing area*

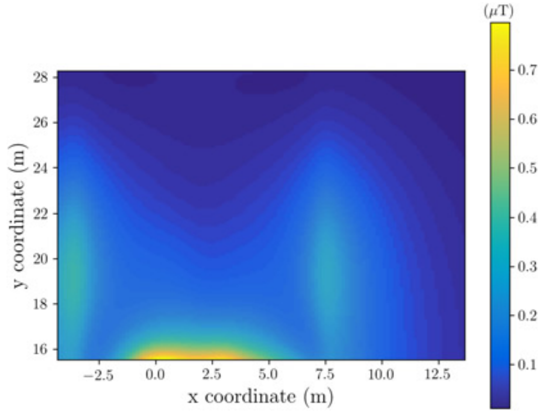

Fig. 9 *Simulated magnetic flux density distribution in the testing area with the shield*

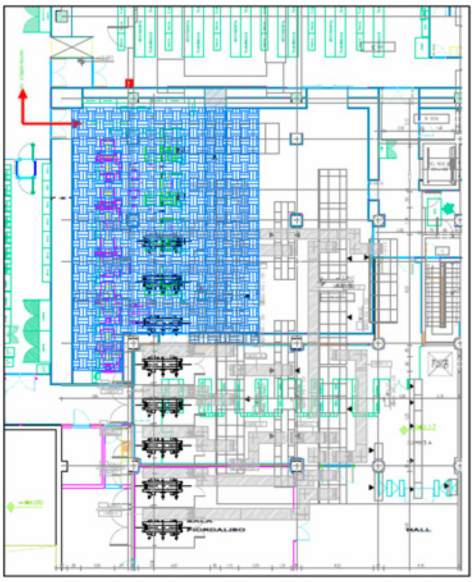

Fig. 7 *Indication of the shielded area*

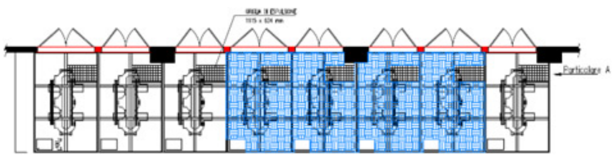

Fig. 10 *Second shielding system directly above the transformers*

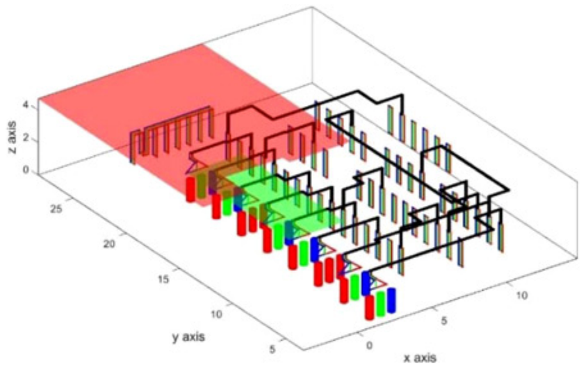

Fig. 11 *3D Model of the substation in presence of the two shields*

The shield simulation makes it possible to obtain above the substation a significant reduction of the magnetic field, even if in some area, close to the shielding boundary, the limit is exceeded (Fig. 9). This is due to the edge effects produced by the shield and the only solution, which was not allowed in the presented application, is the extension of the shield outside the sensitive area.

An alternative solution based on the application of an additional shield placed on the top of each power transformer has been applied (Fig. 10). A new simulation with the two shields (red and green plane in Fig. 11) is performed and the final magnetic field

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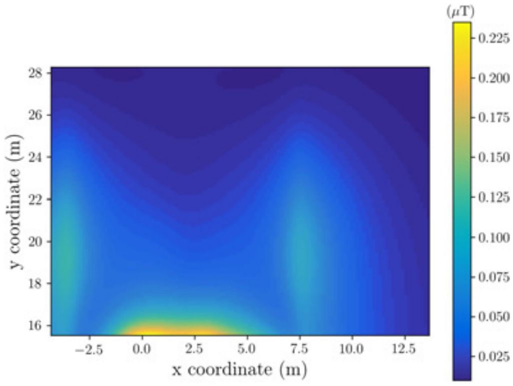

Fig. 12 *Simulated magnetic flux density distribution in the testing area with the two shields*

Fig. 13 *Picture of the first shield: under the floating floor of the testing area*

Fig. 14 *Picture of the second shield: above the boxes of the power transformers*

distribution is shown in Fig. 12. As it can be seen the magnetic flux density globally does not overcame the limit of 0.2 μT.

3.3 Experimental results

After the simulation and design step the implementation of the shielding solution has been done. Fig. 13 shows the installation of the shield at the ground level of the testing area. Fig. 14 shows the

Fig. 15 *Layout of the measurement points*

shield placed above the power transformer boxes. In both the shields aluminium sheets have been welded.

The performance of the shielding system has been tested by experimental measurements performed at nine points as shown in Fig. 15. Three heights have been considered:

- $z = 70$ cm, corresponding to the height where the floating floor of the clean room is installed and so it coincides with the actual floor surface;
- $z = 120$ cm, corresponding to a height of 50 cm from the floating floor of the clean room;
- $z = 170$ cm, corresponding to a height of 100 cm from the floating floor of the clean room.

The results of the entire measurements campaign are summarised in the following tables. In particular, Table 1 includes the magnetic flux density before the mitigation, Table 2 includes the values after the application of the first shielding and finally, Table 3 includes the values obtained with the installation of the second shield.

Table 1 Magnetic flux densities without mitigation (P4, P5, P6 where not available for measurements during the campaign)

	B, μT; *Z* = 70 cm	*B*, μT; *Z* = 120 cm	*B*, μT; *Z* = 170 cm
P1	0.96	0.92	0.92
P2	1.23	1.18	1.17
P3	2.55	2.13	1.96
P4	—	—	—
P5	—	—	—
P6	—	—	—
P7	2.41	2.22	2.22
P8	2.63	2.32	2.17
P9	1.86	1.72	1.62

Table 2 Magnetic flux densities after the installation of the first shield

	B, μT; *Z* = 70 cm	*B*, μT; *Z* = 120 cm	*B*, μT; *Z* = 170 cm
P1	0.09	0.10	0.11
P2	0.09	0.09	0.09
P3	0.10	0.13	0.14
P4	0.15	0.16	0.18
P5	0.42	0.37	0.35
P6	0.66	0.59	0.54
P7	0.23	0.22	0.22
P8	0.26	0.26	0.27
P9	0.98	0.72	0.62

Table 3 Magnetic flux densities after the installation of the second shield

	B, μT; *Z* = 70 cm	*B*, μT; *Z* = 120 cm	*B*, μT; *Z* = 170 cm
P1	0.19	0.18	0.18
P2	0.16	0.14	0.14
P3	0.16	0.15	0.15
P4	0.17	0.17	0.17
P5	0.27	0.25	0.24
P6	0.44	0.41	0.35
P7	0.23	0.22	0.21
P8	0.22	0.21	0.22
P9	0.51	0.37	0.34

As it can be seen, all the measured values are quite in good agreement with the expected results from simulations.

4 Conclusions

In the paper, the problem of high performance magnetic attenuation of sensitive areas with open shields is presented. After a brief description of crucial points regarding open shields, a couple of applications are presented and discussed. The obtained results show the capability of open shields to get the required performance and some critical aspects can be found in practical situations.

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