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Effects of Environmental Phenomena on EMC Measurements

Maklári Dávid[1], Bodolai Tamás[2]

[1]*ÉMÁSZ Hálózati Kft, Miskolc, Hungary, davidmaklari@gmail.com, +36204204942*
[2]*University of Miskolc, Miskolc, Hungary, eikbodo@uni-miskolc.hu, +36308494263*

***Abstract* – The EMC (Electromagnetic Compatibility) is one of the most important sectors in electronic industrial and in retail area as well. As more devices and "gadgets" are connected to network via wireless communication as more challenging to avoid any malfunctioning during normal operation. The main focus is to determine how much noise come from our devices and how much they can be immune to noises before causing any problem in their normal operation. Because this high sensitivity, reaction and interaction of the environmental factors - building - EMC chamber – measurement equipment and UUT (unit under test) as a whole system should be deeply understood and analyzed. One of the most important such problems is the earthing of the chamber and the building. As a requirement of Albatross Projects GmbH (manufactureer of University of Miskolc EMC chamber), the chamber needs an earthing point with less than 1 Ohm. As well-known as less the grounding resistance as better the performance. But the question is how the effect of the grounding resistance can be determined and calculated. The difference between 1.1 Ohm and 0.9 Ohm matters in the practice. In many cases EMC chambers are installed into an existing building where this 1 ohm can be hardly achieved therefore relation between resistance value and the measurement performance should be determined.**

***Keywords* – EMC; earthing resistance; environmental effect;**

I. INTRODUCTION

In this year at the University of Miskolc an EMC chamber has built up. The EMC laboratory contains a SAC-3 type chamber, which is suitable for automotive and commercial industry measurement. The implementation of the building is done according the requirements of Albatross. We measured the earthing resistance at the building and the result fits.

The chamber is installed in a newly constructed building which is built specially to accommodate the EMC laboratory. Therefore, we can tell, that the building is constructed directly according to the technology specifications. The technological specification effecting the building parameters in case of an EMC laboratory can be divided into two parts. One is the specification of chamber, and one is the specification of instruments used with the chamber. Besides of several others, the two most critical requirements of building are the specification of basement of the chamber and the grounding resistance of the building.

The first requirement is load capacity and flatness of the basement, which is not the subject of this paper. This paper deals with the grounding resistance problem of the building.

In general cases in construction industry at most of the buildings the earthing resistance must be less than 50 ohm, however EMC chamber developing companies demand less than 1 ohm resistance for the building for their chambers. This unusual requirement rises several questions.

Comparing the two values (50 ohm and 1 ohm) and taking into account the practical experiences it is hard to say that this value cannot be just ignored at the design phase of the building. The first point is, that grounding resistance of a building less than 1 ohm is not an easy target, and requires special knowledge of design and development. To achieve it has to be considered a lot of influencing parameters. The chamber(s) earthing is mostly common with the building earthing, therefore the influence on the chamber is evident. We also know, that the earthing is the first step in construction process, it precedes the building's basement construction. It means that if the basement is made, a big part of the earthing mash is closed, further access is not possible.

Also intermediate measurements are limited before the basement constructions because the resistance will change the value when the building is ready. Therefore, professional design and accurate installation of the earthing is highly essential in such buildings.

The question is can we rest easy if we have less than 1 ohm earthing resistance? Unfortunately, the answer is no. Alone less than 1 ohm resistance is not enough. The power network system of the building and of buildings in the near environment are also influence the performance of the chamber.

We also cannot forget about lighting protection system what is closely related with the earthing system.
What is the relation between earthing resistance and the parameters of the chambers? At first look we should just take really much care of providing the requirements, but what is about being at the other side of the horse (somehow reach less than 0,1 ohm) or even "worst" being at an earthing resistance value above 1 ohm.

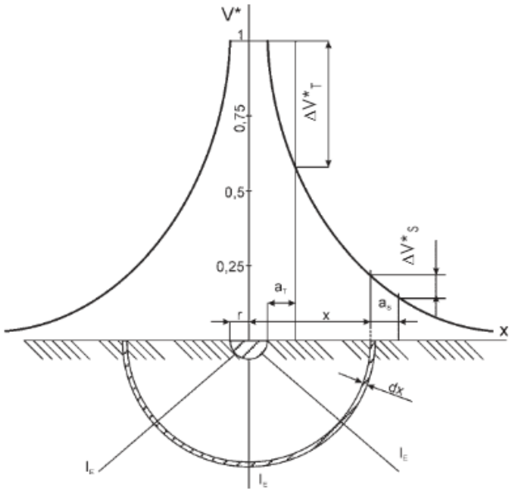
II. PREVOIUS SIMULATION RESULTS [4]

In many cases environmental circumstances and parameters needs to be considered. One of the most obvious phenomenon is the rainy weather. It definitely has high impact to our earthing resistance value, because as it well known, the earthing resistance value depends not only on the amount of the rain but the combination of the direct earth. To study different effects to earthing resistance we have developed a simulation model of the building with its earthing system. We have run the simulation with a wide range of earthing resistances of the building with different possibilities of the environmental factors. The ground under the building can be very different, and it can contain several different geodetic layers. It can be a gravelly, clayey, sandy or a quasi-normal ground, or their combination. In Table 1 contains the ranges of resistivity for the different soil types.

1. Table Resistivity of different soil types [1]

Soil Type	*Resistivity range [ohmm]*	*Resistivity avarage [ohmm]*
marsh	*2-50*	*30*
clay	*2-200*	*40*
mud	*20-260*	*100*
sand	*50-3000*	*200(wet)*
peat	*>1,200*	*200*
pebble sand	*50-3000*	*1000(wet)*
rocky soil	*100-8000*	*2000*
concrete	*50-8000*	*275*

The best type of the earth for earthing system, which is containing the most valuable items, like minerals, nutrients and delicacy in all over the world. Therefore, this type of earth is the best to achieve an appropriate earthing resistance. Unfortunately, there is no such land composition everywhere where EMC buildings are built, just as it is not under our building. Off course a real EMC installation project provides good opportunity to answer all questions, which were introduced in this scenario. First of all several theoretical problems should be analyzed. As such measurements are not always, more exactly very rarely possible, and as it was mentioned above it will provide limited information during the construction, the best way to get the necessary information about the designed system performance is the simulation. It will show the feasibility and functionality of the system.
The ANSYS Maxwell module was used for simulation in which we have chosen as Solution type Electric DC conduction, because the software in this scenario make differences between conductors and insulators.
The model used to show the basic relationships is the ground-mounted, ground-sunk hemispherical electrode shown in Figure 1

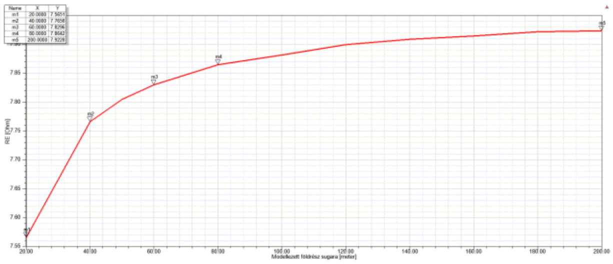


1. Figure The earthing resistance and the potential distribution at the surface is calculated with the hemispherical electrode[1]

$$dR = \frac{\rho}{2\pi x^2} dx \qquad (1)$$

$$R = \frac{\rho}{2\pi} \int_r^{\infty} \frac{dx}{x^2} = \frac{\rho}{2\pi r} \qquad (2)$$

where r the radius of the electrode, x the distance from the centre of the electrode. This model assumes that the resistivity constant, the earth's surface is horizontal and infinite extent. If the radius is 1m and the resistivity 50 ohmm we can determine the resistance value as 7,9578 ohm. In the simulation we designed the electrode and the surrounding earth with an 18x18 segmented hemisphere. The electrode's radius is 1m but the earth's radius is parametrized form 20 m up to 200 m within 20 m step size

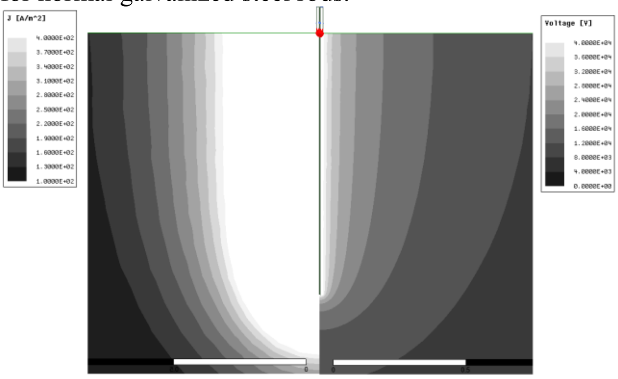


2. Figure Hemisphere electrode in the function of earth's radius

The results show us as we expected the more the radius is extended the more we get closer to the theoretical solution. At 200m radius our result is 7,9228Ω which differs only by 35mΩ from the theoretically calculated value.
The next step was to simulate the behaviour of the standard earthing rod. In the MSZ EN 50522 standard is a formula which helps in calculation of the scaling of the earthing rod.

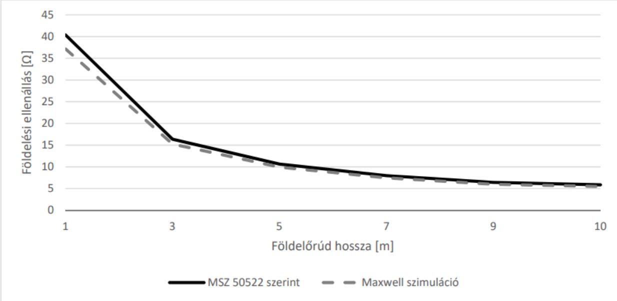
$$R_E = \frac{\rho_E}{2\pi L} ln \frac{4L}{d} \tag{3}$$

where L [m] is the length of the rod d is the diameter of the rod and ρ_E a soil's resistivity. We have chosen the resistivity to 50ohmm, because that fits to the standards as during designing this value has to be used for clayey ground. The earthing rod's diameter is 0,025m, because it corresponds to the commercially available earthing rod. We calculated and simulated in case of 1, 3, 5, 7, 9 and 10 meters' long rods.
In the simulations, the soil around the rods had 100m radius, 100m deep and built up with a regular polyhedron, consisted of 24 segments. The rod's material was chosen as V4A acid resistant steal, which has a conductivity worse than the galvanized steel, but the resistance again corrosion of the galvanized steel is very bad, therefore it cannot be used under buildings. In the formula (3) the resistivity of the rod isn't included, probably because it was developed for normal galvanized steel rods.



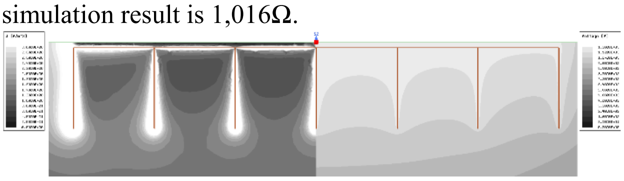
3. Figure 1m long earthing rod's current density (lef side) and voltage distribution (right sde)

Result of simulation with one earthing rod met our expectations in terms of voltage and current density.
Comparison of the results of simulations and calculation by the given Formula (3) can be seen in Figure 4.



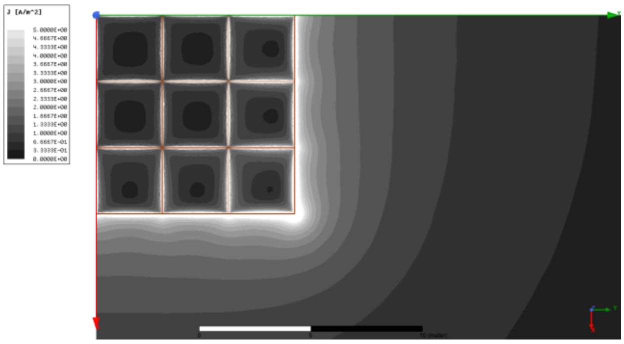
4. Figure Earthing rod's earthing resistance comparison in function of the rod's length

We concluded that the deviation is acceptable and it is decreasing in function of the length. Expressed by numbers the calculated result is 5,87Ω and the simulated is 5,48Ω
Nowadays increasing number of international books and articles about earthing can be reached. In our cases the simulation models are working just fine. We could prove that the formulas and the simulations are met. Also in EMC theme we found a presentation which especially focuses on earthing and shielding. In this article there is an example of implementation of an EMC chamber's earthing. We made deviation a bit in our simulation to reduce the complexity to make comfortable the work. [3]
If we use the formula regarding standard, one rod's earthing resistance is 16,38Ω. Assuming that these do not affect to each other the 49 pcs rod's earthing resistance is theoretically 0,334Ω. In addition, the connection net, which we calculated as 2,12Ω and based on the equivalent circle the result is 3,87Ω. Essentially we expect value between 0,289 and 0,308Ω.
In the simulation we used again V4A as basic material and the rod's diameter of 25mm, while the connection wire's diameter was 10mmm, which came from practice. The simulation result is 1,016Ω.



5. Figure The cut of earthing system's in the middle, vertical plane current density(left side) and voltage densisty (right side) mirrored to each other

Investigate the above figure we realized that the intermediate earthing rods have in terms of sinking less affect, because only the end of the rods can prevail and the rods at the border of the earthing system have much more affect to the earthing. Consequently, we expected that we will get the same behaviour at 2D layout from top of view.

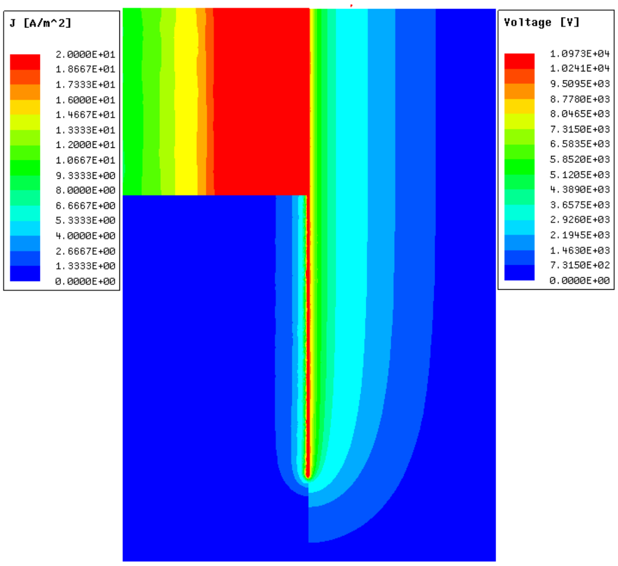


6. Figure Current density of the system from top view

From top view we can see the quarter of the earthing system (take advantage of symmetry the simulation time can be reduced significantly). The connection net doesn't have affect to upwards, because there is almost no soil, to downwards the earthing rods are closing it out. The connection net has participation in earthing resistance only on its district. However it has to be mentioned that this dense? Net is needed because of lightning protection as well.

III. SIMULATION BASED ON SOIL MECHANICS

After the first simulations we had the results from trial drilling and we could analyse how does look like our soil. The results showed us that the soil is layered. The above 4-8 m is clay and under that a few hundred m stone. Unfortunately, this is bad for us, because the stone's resistivity is in range 1000-8000 ohmm depends on the moisture- and salt content. This value is so high that it cannot effectively take participation in earthing. As a result, in vertical way doesn't make sense to extend the earthing net.

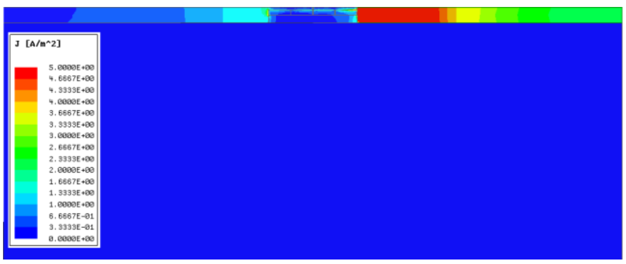


7. Figure Simulation of the soil with clay and stone. Current density at left side, Voltage density at the right side

As Figure 7 show us the soil structure has no effect to the voltage, but the current density at the border of the two layers is extremely reduced.

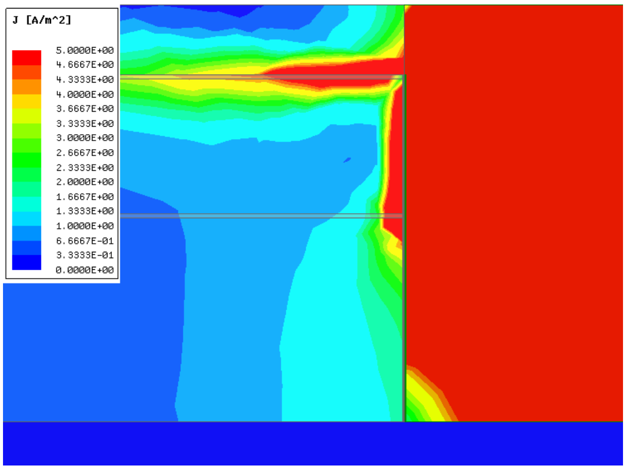
We have found an article about earthing methods and it pointed out that increasing the number of the rods is not the best way to achieve the desired earthing resistance. Instead of that salt pit has to be formed. [5] From other hand the salting of the soil in the geo-electric measurements is a common practice to increase the soil's salt content. Therefore we got the idea to make simulation how this method will behave. Around the building the soil could be salted theoretically, but due the location of the building the area is limited. In the simulation we designated/selected the area behind the building. With parametric test we looked for the resistivity value at which the earthing resistance is 1 ohm. The result is 6,17 ohmm. This 6,17 ohmm has to be reached at the salted clay to achieve the 1 ohm earthing resistance. We have chosen the normal clay's resistivity to 15 ohmm, because we measured several times the soil's resistivity under the building before the installation has started and all result was very close to 15 ohmm. The stone layer's resistivity was 1000 ohmm. We assume that at one side of the earthing net we have the possibility to increase the salt content of the clay.

On Figure 8 the layout is as follows. The earthing net is included into the top bar. The earthing net is placed into normal clay. To the right side of the earthing net is the salted clay. Below all is stone marked as blue rectangle. We can see the behavior of the current. From the color-scale we see that inside the stone layer the current density is pretty much zero. In this simulation we got the same result at the two side of the net as at Figure 5 and Figure 6 which is: at the side-rods have more prevail according to current density. It stands out also that the salted clay has the maximum current density.



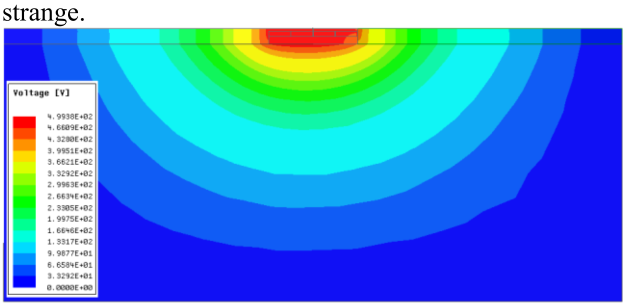
8. Figure Current density at normal clay, salted clay and stone

Below on Figure 9 we see the borders at the three type of soil. The border between the salted clay and the normal clay is placed exactly to the center of the earthing rod.



9. Figure Current density at the border

The current density is extreme in the salted clay. The reason for that is because the resistivity of the salted clay is low compare to the normal clay and as a double effect it is in connection with a side rod.
Figure 10 show us the voltage. At first look could be strange.



10. Figure Voltage

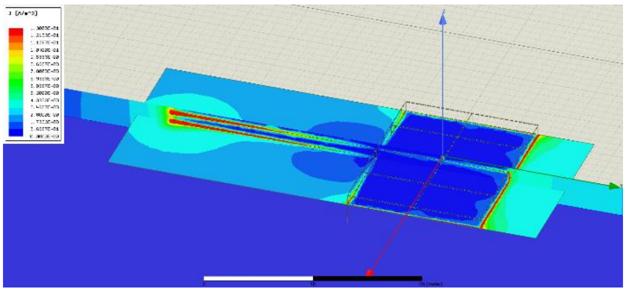
In contrast to the current density, the voltage is symmetric as we expected.

Because the resistivity of the clay is changing even in natural environmental we wanted to make a simulation which shows us what is the effect to the earthing resistance if only the clay's resistivity changes while the layer's thickness and the earthing net doesn't.
The table below contains the results. During the simulation the stone's resistivity was constant (1000 ohmm). Between the resistivity and the earthing resistance is almost linear relationship.

2. Table Earthing resistance in function of the resistivity of the clay

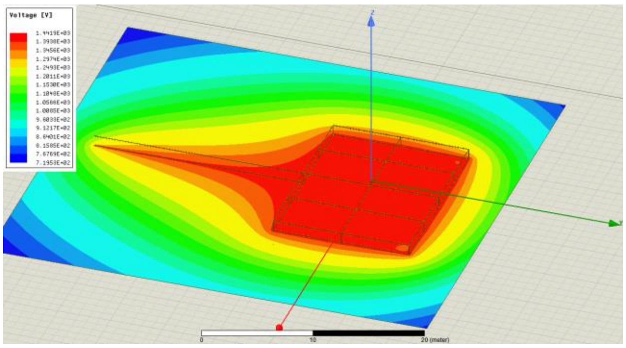
Clay resistivity [ohm]	Earthing resistance [ohm]
50	3,8
33	2,43
15	1,24

Because of the vertical extension of the net didn't make appropriate result, therefore we are thinking on the horizontal extension also. In the below figure to the building's main net was extended with two 80 m long copper wires (10 mm diameter). The resulted earthing resistance is 1,03 ohm.



11. Figure Current density with extended earthing grid

The effect of the extension can be seen in figure 12 regarding voltage. This solution can be advantageous if one building's earth has to be repaired or improve in a later time.



12. Figure Voltage with extended earthing grid

IV. CONCLUSIONS AND OUTLOOK

As it can be seen the simulation and the real measured values are met. We have simulated several contributions of earth and proved that the earthing resistance value may vary, depends on several parameters and not enough to measure just once. We must keep in mind how far we can go if we find a deviation/solution about the measuring accuracy, if we considerate the earthing resistance of the chamber has a lower value than required or what can we accept even if it is above the requirements of the regular value. I think it is really important to have a clear view of all about it, because the wireless connected device's number are growing so quick, that standards must continuously be improved and increase the requirements, however even by the law.
The made simulations based on soil mechanics have contributed greatly to the final design and implementation of the earthing system. From the results it became evident

that the vertical extension of the earthing system is irrelevant, instead of that the horizontal expansion is the best choice. The simulation results about the salted soil are promising but those are not finalized yet. It needs continuous measurements and the leaching salt from the soil has to be supplemented. In other hand the salted soil makes environmental questions too. The copper tongues from the earthing net have good effect to the earthing resistance because those are extending the circumference of the earthing net. However, at the installation of the building we didn’t have the possibility for larger earthworks.
Overall we have chosen a solution, that under the building will be placed the roughly 5 m grid spacing net. Only the net’s side will participate actively in earthing, but the net has a great importance at lightning protection. It is also a lightning protection directive that at this kind of buildings at the corners deep earthing rod has to be used. Because of the soil conditions at the corners were installed 3 m long earthing rods. Additionally, two vertically rod had to be installed for lightning protection because of the length of the building. Above these from the middle point of the building in radial direction at the corner of the building two vertical and at two extra, suitable place were vertical earthing rods pressed, in total of 14,5 m length.
The relevant simulation isn’t done yet, because of limited time, but presumably with this solution the earthing resistance will be stay above 1 ohm. The building’s electricity supply is connected to a transformer approximately 60 m far. It is relevant to mention that in our case the supply came with 5-wire cable compare to the usual 4-wire cable solutions. This means that the PEN is separated to PE (earth) and N (neutral) next to the transformer. This is important because in this way we can connect the earthing of the building without any noises directly to the transformer’s own earth. As the implementation of a transformer has strong requirements, this should be enough to reach less than 1 ohm resistance value. The transformer’s earth unfortunately is connected also to the earth of the other buildings in the area. Consequently at the transformer we have measured less than 0,3 ohm earthing resistance, also with more independent method. In purpose of research the building’s main electric cabinet has been installed, that in case of demand we can use our chamber when it is connected only to the building’s own earth net and also with the transformers earth together. Using the whole earthing net seems like a good idea, but we have to take in consideration that the transformer is connected to the other buildings and unfortunately with 4-wire. The contractor will hand over the building as it complies with current Hungarian rules. This means the earthing system of the building will be connected to the transformer’s earth. In the future we will make additional measurements to determine the effects of the common earth. Our institute has a great past in connection electricity networks, therefore we exactly know, what extent noises can appear on the PEN wire. Finally it is imaginable that we have better performance with a 1,2 ohms pure earth compare to a 0,2 ohms but loaded with noises.

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