Progress In Electromagnetics Research M, Vol. 7, 97–108, 2009

PROTECTION OF CAR-SIZE SENSITIVE EQUIPMENTS USING A SHIELDING COVER

M. M. Danaei

Department of Electrical Engineering
University of Imam Hossein
Iran

H. Aliakbarian

Department Elektrotechnik (ESAT)
Katholieke Universiteit Leuven (KUL)
Belgium

M. Azarbadegan and Y. Bairami

Facluty of ECE
Iranian University of Science & Technology
Iran

Abstract—In this paper, the protection of a sensitive car-size system using a hemispherical shielding cover is discussed. The shield cover spreads on the soil, inserting some vertical (metal) rods into the ground, and adding a gridded wire carpet under the cover structure. The shielding performance of the cover structure was considered by a numerical simulation and experiments. The proposed cover structure shows the shielding effectiveness (SE) of $-40\,\mathrm{dB}$ in worst case in the frequency range of 10 to 200 MHz.

1. INTRODUCTION

By the increase of radio frequency communications, there are a lot of hazards from intentional and unintentional sources. These sources are mostly working in the range of several kHz to hundreds of MHz although increasing in the higher bands. In this work, we consider the range between 10 MHz and 200 MHz.

Corresponding author: H. Aliakbarian (h.aliakbarian@ieee.org).

In this paper, the protection of a sensitive car-size system against electromagnetic waves using a shielding cover in an outdoor environment is discussed. The goal is to design, assemble and test a practical partly hemispherical cover with 10-m diameter to achieve to shielding effectiveness (SE) of more than 40 dB according to system sensitivity level. Generally, small size sensitive equipments are placed inside a box or a bag [1]. Since these sensitive systems are so large to be placed inside a shielded bag or container, we have to offer another scenario to cover them. There are a few practical works published for this problem [2] although there are some suggested methods to increase the shielding of metallic enclosures with an open part [3].

Figure 1 shows a cover in a simple shielding structure, initially proposed. There are some ideas applied on a shielded cloth to improve protection of big equipments. Due to the fact that the covered space is open, soil under the cover has a significant crucial effect and different types of soils can affect the shielding from about zero dB to more than 80 dB discussed in Section 2. First of all, we can spread a ring-style flattened part of the cloth on the soil. This is not enough and it should be improved using other ways. Some vertical rods which pierce the ground and paste the cover to the earth may be further improve the shielding as shown in Fig. 2, but they are also not enough for shielding of more than 20 dB. The required modification is to spread a gridded metallic carpet under the equipment and paste it to upper cover as will be shown in Fig. 8.

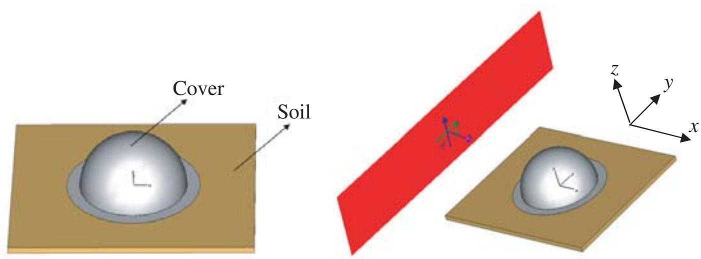


Figure 1. The initial proposed cover structure and the incident plane wave.

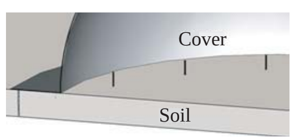


Figure 2. Vertical metallic rods to improve shielding of the cover.

In Section 2 of the paper, we discuss over the different soil effects. The idea of using vertical rods is used in Section 3. In Section 4, to improve SE, a gridded metallic carpet is spread under the equipments and then and approximate simulation is done substituting the grid with a thin lossy sheet. The experimental results are presented in Section 5 and finally the paper is concluded in Section 6.

2. SOIL EFFECT ON SHIELDING EFFECTIVENESS

One of the most important parts of the shielding is the recognition of the soil's electrical parameter in the region. However, the cover should work in different areas. One of the ideas is to change the soils parameters closed to the border of the cover when it is installing. This can be done using water or some special materials such as ordinary salt which is often employed to make artificial low resistance ground. But indeed it is some what hard, time consuming, ineffective, and may be expensive. The cover should work in different soil and weather condition and has to satisfy minimum requirements in the worse case.

Fisher et al. [4] have measured the dielectric properties of many kinds of soils. For some kinds of usual soils, the results of a simple cover shielding with a one meter extra cloth flattened on the soil are depicted on Fig. 3. It is obvious that the effect of σ of the soil is fundamental. Using shale with conductivity, σ (*Siemens/m*) of 0.1 improves the shielding to more than 65 dB while less than 30 dB in

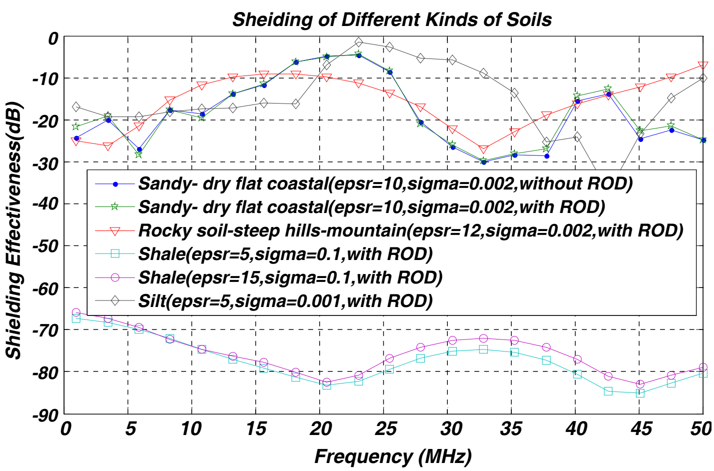


Figure 3. Shielding of different kinds of soils used in a simple shielding structure.

others. In one of the frequencies, the shielding is decreased to −1 dB which is not favorable. The legend of the Fig. 3 shows that the relative dielectric constants of the soils vary from 5 to 15 and the conductivity from 0.001 to 0.1 and also the shielding varies significantly as the dielectric property changes.

3. VERTICAL RODS IN THE GROUND

The second suggestion of shielding increment is to add some vertical rods in the groundlike some nails. The nails reduce the leakage of the wave from the soil section under the ground and strengthen the cover in the ground. It is clear that there is some decrease in received signal in the cover when we increase the number of rods, but how much is the benefit and how many rods are efficient?

To investigate this, it is decided to use dry flat coastal sand with dielectric constant of 10 and conductivity of 0.002 which has the bad shielding effectiveness of −4 dB. If we can improve the shielding for this type of soil, it will automatically be better for other types. The effect of number of rods on the shielding effectiveness of the cover is investigated using CST Microwave Studio 5. Some probes are placed in the cover in different heights and they measure in three directions, x, y, and z. The calculated signal of the worst probes in the center of the cover is depicted in Fig. 4 to Fig. 6 for two sub-bands of 10 to 50 MHz and 50 to 200 MHz for different probes. Other probes detect lesser levels of signal compared to these three probes. One of the definitions

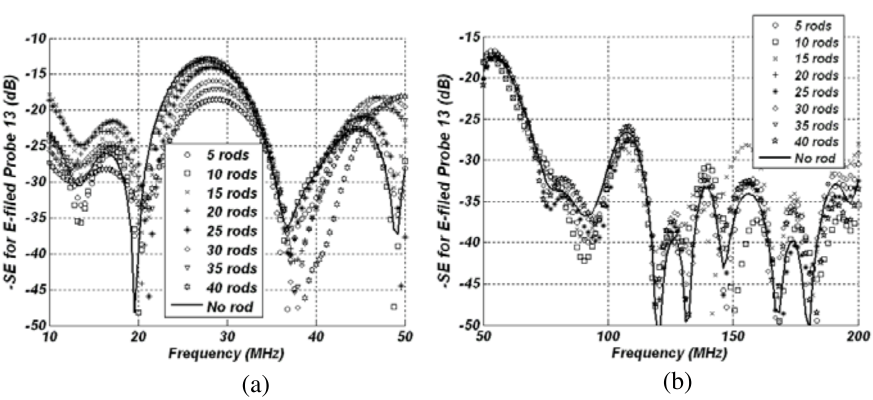
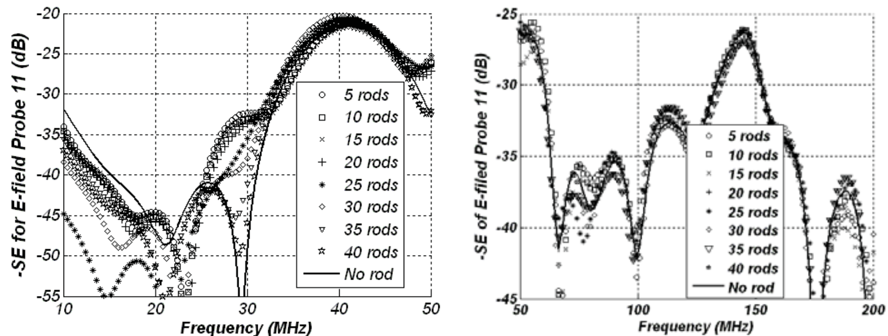


Figure 4. Calculated E-field in the center of the cover using vertical rods (Probe No. 13 (10 cm height from the ground directed in z direction)) which is equal to SE. (a) 10 to 50 MHz, (b) 50 to 200 MHz.

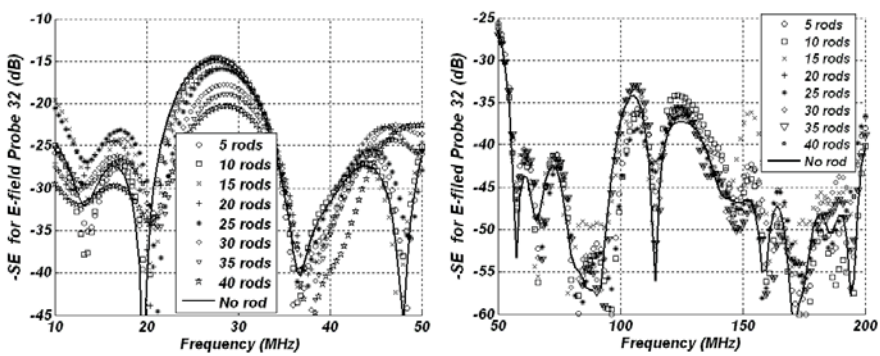
of SE is the difference between the detected values of the E-filed in the presence and absence of the cover [5]. Thus, as the value of the E-filed in the absence of the cover is equal to the 0 dB, the detected E-field in Fig. 4 to Fig. 6 represent *SE*.

It can be seen that the level of the signal reaches to −15 dB. Fig. 4 shows that the increase of rods from 5 to 40 will change the minimum shielding by 5 dB in lower frequency band between −13 dB to −18 while it has no considerable effect in the upper band 50 to 200 MHz.



(a) (b)

Figure 5. Calculated E-field in the center of the cover using vertical rods (Probe No. 11 (10 cm height from the ground directed in x direction)) which is equal to *SE*. (a) 10 to 50 MHz, (b) 50 to 200 MHz.



(a) (b)

Figure 6. Calculated E-field in the center of the cover using vertical rods (Probe No. 32 (1 meter height from the ground directed in z direction)) which is equal to *SE*. (a) 10 to 50 MHz, (b) 50 to 200 MHz.

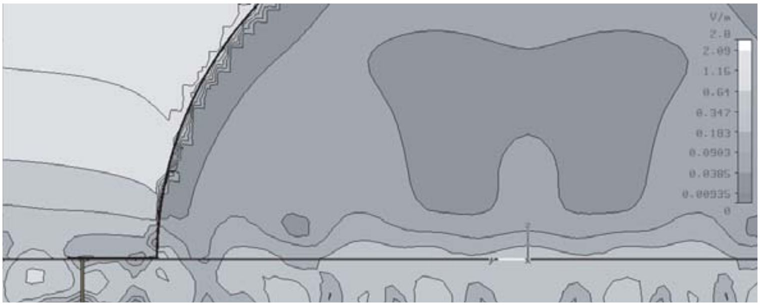


Figure 7. E-field distribution in $x = 0$ plane (100 MHz) after installation of 20 rods.

This is apparent because of the fact that the high frequency wave doesn't sense the rods barrier owing to small wavelength while they block the waves with large wavelengths. Probe number 11 doesn't demonstrate more than 2 dB changes in shielding for lower band and less for upper band for different rod numbers. Also, probe number 32 shows 7 dB changes in minimum shielding between −14 dB to −21 dB. It is important that the worst frequency in probes number 13 and probe number 32 is around 28 MHz. The frequency is near the resonance frequency of the cover if assumed as a hemispherical cavity. Fig. 7 shows the distribution of E-field inside and outside of the cover for $x = 0$ in the 100 MHz frequency for the case that 20 rods are selected. It is seen that the intensity is higher in the center but this is changed in different frequencies. The penetration of the wave into the cover is visible at the margin of the soil and the space inside the cover. The waves are penetrated from all point specially cover's edge.

4. EFFECTS OF GRID UNDER THE COVER

The final method to increase shielding of the structure is to use grided ground carpet under the equipment. The grided carpet in the floor should be sustained to bear heavy weight of equipments without tearing. The grided carpet should be pasted to the upper cover with some pins which can be the vertical rods mentioned in Section 2. The selected copper shielding cloth [6] has wire diameters of 0,2794 mm and aperture of 1,309 mm which has open area of 67.9% and 0.142 pounds per square foot weight.

One of the main problems of the work is to simulate the cover system including grid details. The grids' size is about some millimeters while the total structure is about 10 m and the wavelength is from

60 cm to 30 m. Thus, practically it is impossible to mesh the whole system considering the small grids about 0.0001 times of the total structure while at least 10 meshes per each of the square grids are needed. That is why many efforts are being done to speed up calculation time for structures with relatively small details [7]. On the other hand, we have *SE* of grided clothes using accurate tables of the data sheet. The purposed idea is to use a sheet of lossy metal in the full wave simulation which represents the gridded metallic carpet with equal *SE*. But it is known that shielding behavior of a gridded carpet and the lossy metallic sheet are not similar in frequency domain. In fact, as it can be observed in Fig. 8, the *SE* of a grid decreases with frequency increment while it is vise versa for a metallic sheet. Thus, the working frequency range is divided to six sub-bands which approximately have constant *SE* within the ranges illuminated in Fig. 8. The sub-bands are 10 MHz to 20 MHz, 20 MHz to 40 MHz, 40 MHz to 60 MHz, 60 MHz to 90 MHz, 90 MHz to 135 MHz, and 135 MHz to 200 MHz. For each range, a 5 cm thickness thin sheet with ε_r and μ_r of 1 is used which has different σ. The σ coefficients are 8.8 13, 20, 30, 45, and 90 for the lower band to the upper one

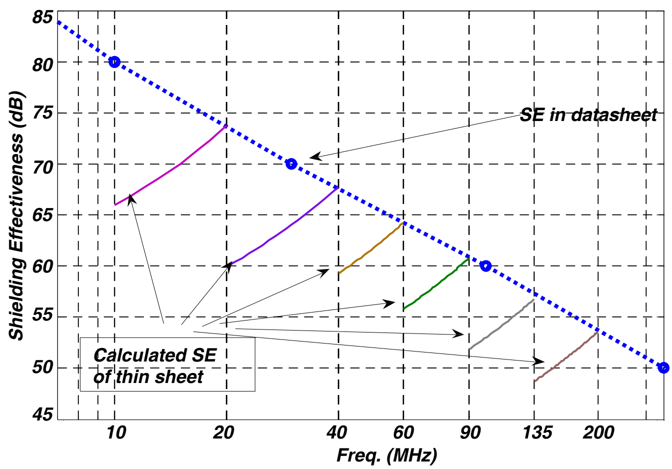


Figure 8. Shielding effectiveness of the used wire cloth, and the shielding of the substituted thin sheets in six sub-bands.

respectively. To calculate *SE*, Eq. (1) from [8] is used.

$$SE(d) = RdB + A(dB) + MR(dB)$$
$$= 20\log\left|\frac{(\eta_o+\eta)^2}{4\eta\eta_o}\right| + 20\frac{d}{\delta}\log e + 20\log\left|1-\left(\frac{\eta_o-\eta}{\eta_o+\eta}\right)^2 e^{-2\frac{d}{\delta}} e^{-2j\frac{d}{\delta}}\right| \quad (1)$$

RdB, *AdB*, and *MRdB* are reflection loss, absorption loss and multi-reflection loss factors. d, δ and η are thickness, skin depth, and characteristic impedance of the environment, respectively.

Therefore, the simulation is done in each range separately. Since the installation of the cover system is difficult, some gaps between upper and lowers parts of the cover appear in practice. Pessimistically, a slot is emerged around the cover entirely, but the vertical rods connect both parts frequently and divide it to many. Thus, it is assumed that there are some slots placed uniformly around the cover with a thickness of 1 cm.

Figure 9 shows the cut view of the cover's side, including spread cover, vertical rods, and the substituted thin sheet having 1 cm distance from the upper cover. The vertical rods attach the upper and the lower parts electrically and mechanically.

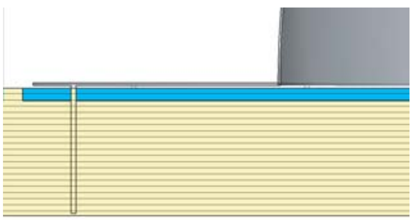


Figure 9. The cut view of the covers' side.

Figure 10 presents the maximum magnitude of detected signals in different probes placed in the cover center. It can be seen that, the minimum shielding is better than −40 dB in the entire band while the *SE* is calculated pessimistically. Although the cover obstructs the wave to be inserted in any media, to set it up as a shelter is a hard problem and −40 dB shielding seems to be very good. The *SE* is better at the lower frequencies due to the fact that the wave can not penetrate through the gap between the both parts far below gaps resonance frequency.

The discrete parts of the plot are the margins of the frequency ranges. The approximations in these locations are the most in the lower bound and are the least in the upper bound. This is due to the fact that the *SE* of the substituted thin sheet matches with the *SE* of a real wire carpet in the lower bound of the margin and are distant at the upper bound. The maximum error of the calculations can be approximated by the difference between real *SE* of the wire mesh [6] and the simulated thin dielectric in Fig. 8 more visible in margin frequencies, at 20^+ MHz, 40^+ MHz, 60^+ MHz, 90^+ MHz, and 135^+ MHz. 20^+ stands for frequencies slightly more than 20 MHz. Fore example, the maximum jump in the Fig. 10 is +13.5 dB at 20^+ MHz. In this frequency, as can be seen in Fig. 8, the simulated sheet has 60 dB shielding instead of 73.5 dB in 20 MHz. Therefore the simulated penetration to the cover in this frequency should be more than the accurate case. This is confirmed in the Fig. 10, because the accurate simulation in the upper bound of the [10 MHz to 20 MHz], namely 20^- MHz, shows −68 dB shelding for the cover while the approximated simulation at 20^+ MHz shows +12 dB increase in the shielding of the cover to −56 dB. Thus, the shielding plot of the Fig. 10 is the worst case and is reliable. Adding up the simulation, the *SE* of the structure is better than −40 dB in the entire band.

The only important factor ignored in the above calculations is the difference between diffraction of the real mesh grid and the simulated thin sheet. As ignoring the factor also will increase the penetration, the Fig. 10 is still the worst case and is reliable. Fig. 11 illustrates the *E*-field distribution inside and outside the cover for the case which 20 rods are installed and a grid is put under the cover. It is obvious

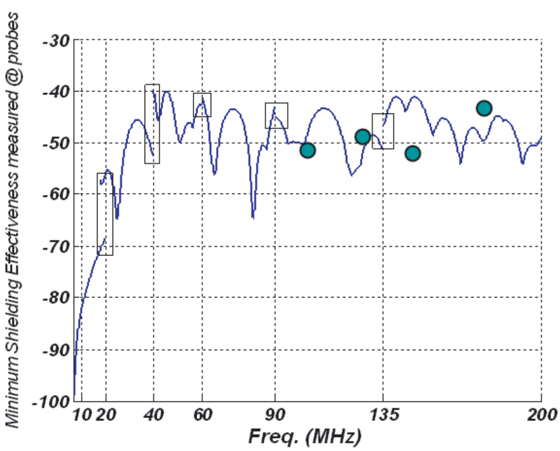


Figure 10. Final total shielding resulted from maximum measured signal, simulation (solid line) and measurement (circles).

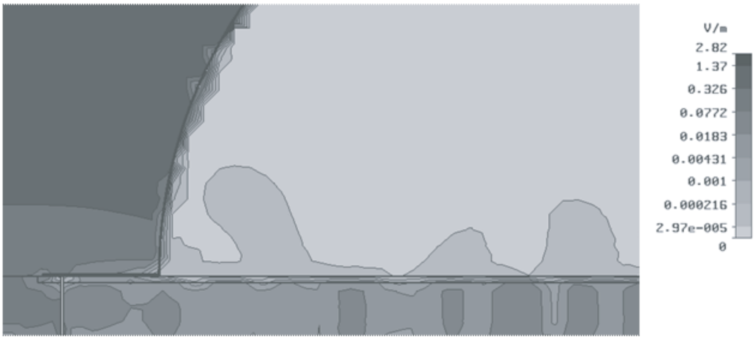


Figure 11. E-field distribution in $x = 0$ plane (100 MHz) after putting grids under the cover (20 rods).

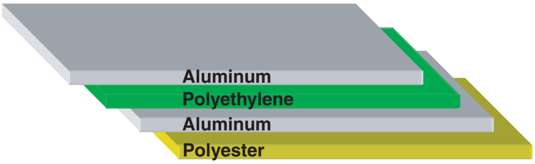


Figure 12. The different layers of the cover.

the distribution is approximate especially for edges and places where the interaction between the grid, cover and soil important. However, it shows that the intensity of the field is highly suppressed inside the cover.

5. EXPERIMENTAL TEST

In order to practically test the design, the special cover with a 1 meter extra flattened part is produced. The cover material is composed of a 4 layer stuff, aluminum 10 µm, polyethylene 12 µm, aluminum 10 µm, polyester 12 µm sketched in Fig. 12. To install the mesh carpet is spread on the ground firstly and then the equipments are placed on it. The upper cover is held on the equipments and finally, using the rods, the upper and lower parts are pasted together. Due to high cost and more firmness, a similar mesh with the same aperture and open area dimensions is used for the carpet under the cover. The used soil in the experimental test was not ideally dry flat coastal sand. Also it was not possible to measure the dielectric properties of the used soil with a good accuracy. However, basically the *SE* is supposed not to be sensitive to small changes in soil dielectric constant while we have used a gridded metallic carpet on the ground. In addition, the cover should work in different environments with different soil properties.

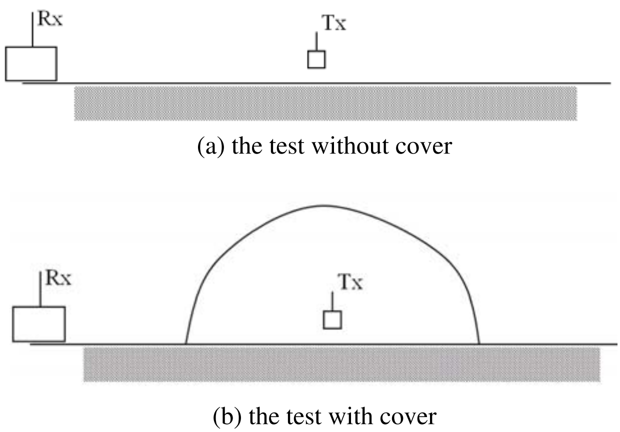


Figure 13. The setup for *SE* measurement.

In order to measure *SE*, we change the place of transmitter and receiver which is acceptable due to reciprocity theorem. The measurement setup is shown in Fig. 13 with two different tests, one without cover and one with the cover. Subtracting the magnitude of received signal in the receiver in two tests, the *SE* is achieved. The results of the measurement in four single frequencies show relatively good match between simulation and measurement. The differences are mainly due to difference in soil properties, none-hemispherical dome of the cover. Moreover, the appeared slots between the upper cover and the gridded carpet are normally shorter than our assumption in the simulations shown in Fig. 9. This might have caused better measurement results in some of the frequencies.

6. CONCLUSION

In this paper, the shielding effectiveness of $-40\,\mathrm{dB}$ in worse case and $-50\,\mathrm{dB}$ in average is achieved employing the practical techniques to set up a cover system on the ground for care-size sensitive systems. The method is based on the spreading of the cover on the earth, using some vertical rods, and employing a grided wire carpet under the system. To achieve to high levels of shielding in a wide range of frequencies, it is necessary to block the leakage of wave from soil. To overcome the problem of grid simulation, a sheet of lossy metal with equal *SE* has been used in the simulation of the whole system.

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