EXAMINING THE EFFECTIVENESS OF EM SHIELDING MATERIALS AND METHODS FOR PRACTICAL APPLICATIONS

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Abstract

Conventional methods to shield components are typically made of solid metal which is heavy, boxy and rigid. This paper reports on the Shielding Effectiveness (SE) of a lightweight and flexible alternative such as metallized fabrics, alloy fabrics and metal mesh in a practical solution. The SE of a planar material is typically too idealistic and unable to accurately represent the actual SE when implemented into a product due to seams and apertures. To better evaluate the alternative materials and their SE for practical implementation, a Remote Control (RC) vehicle is used as the subject of investigation. The shielding materials are applied to the critical components of the RC vehicle and the SE is measured by the difference in emission before and after applying the shield.

Introduction

EMC pursues three main classes of issue. *Emission* is the generation of electromagnetic energy, whether deliberate or accidental, by some source and its release into the environment. EMC studies the unwanted emissions and the countermeasures which may be taken in order to reduce unwanted emissions. The second class, *susceptibility*, is the tendency of electrical equipment, referred to as the victim, to malfunction or break down in the presence of unwanted emissions, which are known as Radio frequency interference (RFI). *Immunity* is the opposite of susceptibility, being the ability of equipment to function correctly in the presence of RFI, with the discipline of "hardening" equipment being known equally as susceptibility or immunity. A third class studied is *coupling*, which is the mechanism by which emitted interference reaches the victim.

To ensure EMC in all the three classes, one of the most common and simple ways to block the emissions of these EM waves is via the use of a Faraday's Cage. However, while simple in concept, even this solution comes with many complications. Traditionally, materials like silver, copper, iron, nickel and other metals are used to make Faraday's Cages. However, these are usually very heavy and require a significant amount of material to make an almost impenetrable shield. There are also implementation challenges especially for irregular shapes. Thus, researchers have endeavoured to find better materials which are lighter, cheaper and have just as much, if not higher, SE with the ultimate aim to get as close to an impervious environment to external EM interferences. However, these attempts have not been very successful. The materials created were either too expensive, too rigid or did not have as good of a SE.

The most common commercial applications of flexible EM shielding in the current era are Faraday bags and Faraday pouches which prevent RF signals from being transmitted from and to one's phone or credit cards. They are made with conductive fabrics and often lined with metal mesh. These are growing more and more popular and many more companies are designing their accessories with these EM Shielding properties to protect their customers' data. However, they are also very expensive and the price of a simple Faraday's pouch starts from around 8.50 SGD.

As such, we hope to investigate the possibility of utilising such a flexible material as a retrofit to an existing product to increase its SE and yet not increasing the weight and cost unnecessarily. We will do this by shielding a RC vehicle for it to function in a high EME environment without any effect on its functionality or performance. The aim is to compare the performance among different choices of flexible materials and recommend one which is able to provide a lightweight solution without compromising the SE requirement.

Materials

A variety of flexible materials as shown in Table 1.1 were tested. These materials are all either metallic, conductive, or both.

Material	**Description**	**Link**
Copper Tape	A thin layer of copper with an adhesive on one side.	【HSE】 5-80mmx10m Copper Tape Foil Repellent Tape Shielding Tape Self-adhesive | Shopee Singapore
Copper Mesh	Loosely interwoven copper threads to form a mesh	12.7CM*3M snail-proof copper wire mesh woven copper mesh used to fill holes and seams to protect plants | Shopee Singapore
Copper Fabric	A cloth-like material made from a combination of copper, nickel and RFID fabric	Antimagnetic Cloth Copper Shielding Fabric-Blocking RFID Radiation 100*110cm Making anti-static cloth High quality | Shopee Singapore
Aluminium Tape	Aluminium foil with a thin layer of adhesive.	[SG Ready Stock] Aluminium Foil Repairs Adhesive Sealing Tape Thermal Heat Resistant Tape Premium Quality 100% Authentic | Shopee Singapore
Silver Fabric	A cloth like material similar to copper fabric	Blocking RFID Singal Wifi EMI EMP 1Meter Protection Pure Copper Fabric-Blocking RFID Radiation Blocking Shield | Shopee Singapore
Aluminium Foil	The aluminium foil found in most grocery stores.	[TEB] Aluminium Foil Extra Thick For Baking, Cooking, Freezing, Wrapping, Storing, BBQ, Grilling, Roasting Kerajang Alum | Shopee Singapore
RFID fabric	A thin fabric made of metal fibres	1x Anti-Radiation Shielding Blanket Fabric RFID EMF Protection Blocking Cloth | Shopee Singapore
Black Fabric	A fabric made of PET/Ni+Cu+Ni	Radiation-proof Fabric 5G Signal WIFI EMF EMI Shielding Anti Radiation RFID Blocking 1*1.1m Supplies High Quality | Shopee Singapore
Conductive Fabric tape	A layer of polyester fabric, Nickel-Copper, plated on one side with an adhesive on the other side.	Conductive Fabric Tape / EMI Shielding Tape - Redtec Industries

Table 1.1

Method

The first method was to wrap the whole vehicle in a shielding material of choice. Aluminium foil was chosen as it was easy to wrap around the vehicle and it is a non-ferrous nature of high-conductivity, which presents itself as a good shield. However, this solution turned out to be impractical as it impeded the functioning of the RC vehicle.

Another approach which eventually proved to be more practical was to dismantle the car and shield the individual components instead. Components that needed to be shielded were determined using a near field probe. The near field probe was connected to a spectrum analyser that allowed us to "sniff" around the enclosure to identify the source of emissions. From investigation, it was found that the source of emissions was the Printed Circuit Board (PCB), and the interconnecting wires. Emissions from the PCB were mainly from the motor connections and the ICs where the capacitors or the resistors are located. Emissions from the motors were found to be insignificant as they were already encased in metal which effectively provided a protective case from EMI emissions. Instead of shielding the whole components fully, it was decided to only shield the higher emissions parts so as to minimise the weight and cost.

Emissions measurements were carried out with the RC vehicle in a GTEM cell. To ensure a constant test setup, a Styrofoam mould, as shown in Figure 2.1, was constructed to place the components in during each run of the test.

Figure 2.1

Experimental method - preliminary testing using near field measurements

PCB

There are 2 possible methods to consider when shielding the PCB.[2]

i. Wrapping the entirety of the PCB with shielding materials as shown in Figure 2.2.
   A box was designed and 3D printed using PLA+ to house the PCB perfectly with apertures for the interconnecting wires. To shield it, the box was wrapped with each material of interest before placing it in the GTEM cell to measure its emissions.

ii. Only covering certain parts of the PCB which had more emissions as shown in Figure 2.3. These included the IC Chips and the points of connection of the wires in the PCB. Electrical tape was also used to provide a layer of insulation to prevent the conductive materials from coming into contact with the PCB which may potentially cause a short circuit.

 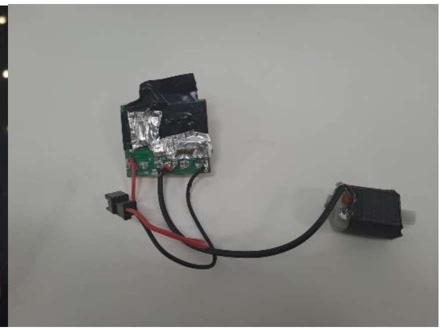

Figure 2.2 Figure 2.3

Motors

The motors had an existing metal casing which helped reduce emissions from the circuitry. From the emissions measurement, it was verified that the emissions from the motors were the lowest among the components under test. While the RC vehicle had three motors, testing was only conducted with one motor connected to the PCB on the assumption that the solution could be replicated to obtain the optimal set-up for the final product. This was done to prevent the wastage of materials as well as reduce the time spent on making each set-up.

The motor was covered using insulating electrical tape to prevent any short circuits before placing any conductive materials on it. Afterwards the layer of conductive fabric tape was pasted onto the motor before carrying out the emission measurement.

Wires

From previous research, grounding is widely recognised as a method to reduce the emissions of the vehicle. [4] As such, we used a copper wire and coiled it helically around the wires before covering the wires in the shielding materials under test. The whole shield was connected into one system and then grounded to a piece of copper tape which served as a grounding plate.

<u>Refitting of the PCB holder in the RC Car to accommodate for the shielding</u>

Originally, the PCB was held in place by multiple prongs within the internal box of the PCB. The original design limits the methods in which we are able to shield the PCB from external EM interferences. Hence, the prongs were removed to make way for a new customized box which was 3D printed as shown in Figure 2.4.

3D printing can ensure the box can be made to its specific dimensions and shape. Coupled with its ability to print irregular shapes, 3D printing can help to provide a structure for the conductive shielding materials to stick on and prevent short circuits from happening.

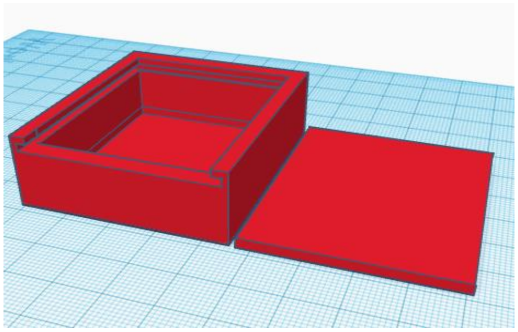

Figure 2.4

Formula for Shielding Effectiveness (SE)

We calculated Shielding Effectiveness via the formula:

Shielding Effectiveness (SE) = Signal strength before shielding **-** *signal strength after shielding*

Inaccuracies during testing

A GTEM cell was used to remove external interference hence providing the most accurate emission profile of the test object. However, the RC vehicle can only function fully via a Remote Control frequency of 2.4GHz. Hence, the GTEM cell door was left slightly ajar to allow this 2.4GHz communication exchange. This introduces some additional emissions as shown by the circled regions in Figure 3.1 which will be ignored in our analysis.

Spectrum Analyser Settings

The Resolution Bandwidth (RBW) and Video Bandwidth (VBW) were both set to 100kHz. The sweep point number was set to 501. The reference decibel level was set to -20dBm. The sweep time was set to 0.1s. The span was from 10MHz to 1GHz. The centre frequency was set to 505MHz. The connections between the cables and GTEM cell were securely tightened using a wrench so as to prevent inaccuracies due to poor connection.

Results

Comparison of Materials

Figure 3.1 shows the graphs of the raw data of the PCB emissions while Figures 3.2, 3.3 and 3.4 show the calculated SE of each of the different materials. For ease of comparison, the graphs were split into three groups of three before the best of each set was compared against each other in Figure 3.5. As can be seen from Figure 3.5, the Aluminium Tape is most effective at shielding from about 200MHz to 400MHz while the conductive fabric tape is most effective from about 400MHz to 1GHz. We suspected that this is due to the more conductive nature of both the aluminium tape and the conductive fabric tape, especially in comparison to the other materials, as well as the fact that most of the other materials seem to have apertures in them. For example, the fabrics have small apertures which could cause some EM emissions to leak through. The conductive fabric tape, while has fabric in it, likely has much smaller apertures due to the adhesive preventing the apertures from widening.

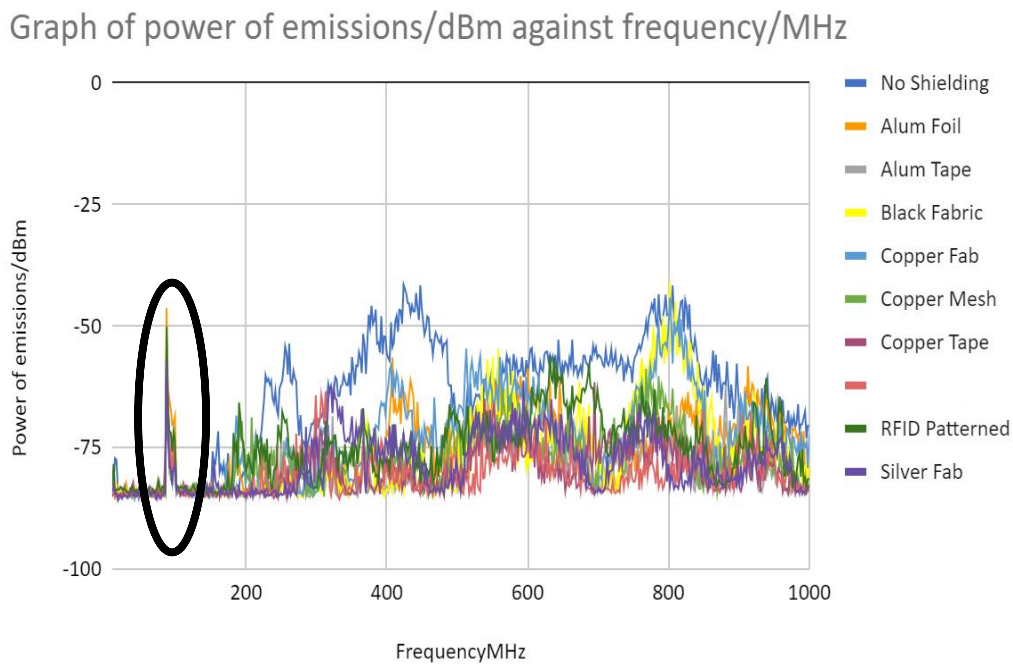

Figure 3.1 Graph of power of emissions/dBm against frequency/MHz for the set-up in Figure 2.4 while being shielded by different materials.

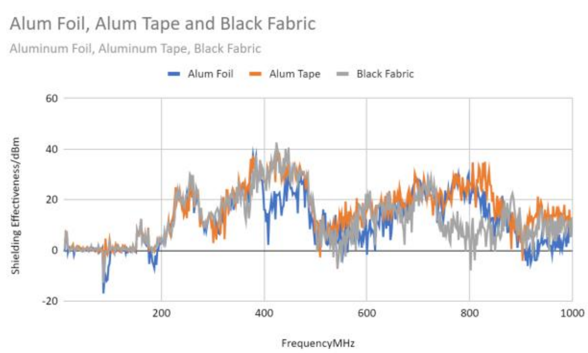

Figure 3.2 Graph of SE/dBm against Frequency/MHz for Aluminium Foil, Aluminium Tape, Black Fabric

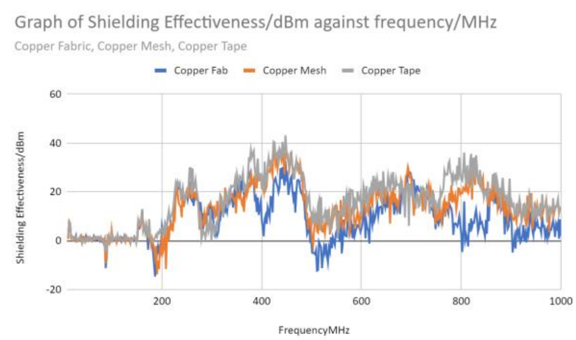

Figure 3.4 Graph of SE/dBm against Frequency/MHz for Conductive Fabric, RFID Fabric and Silver coloured Fabric

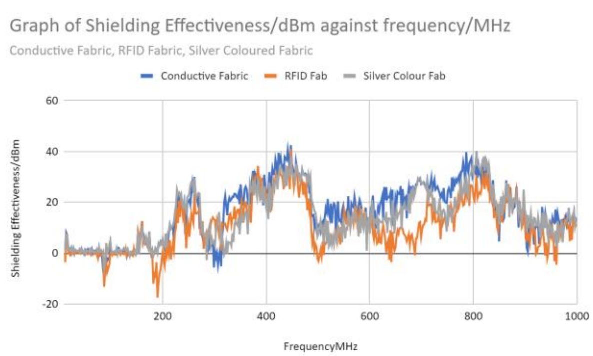

Figure 3.3 Graph of SE/dBm against Frequency/MHz for Copper Fabric, Copper Mesh and Copper Tape

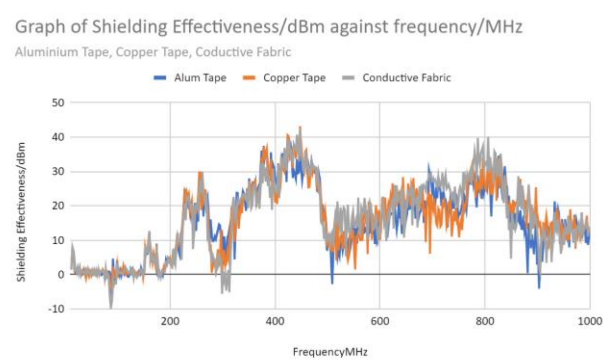

Figure 3.5 Graph of SE/dBm against Frequency/MHz for Aluminium Tape, Copper Tape and Conductive Fabric

Since conductive fabric tape and Aluminium tape were the best at shielding for the different ranges, we further added more layers of these materials to evaluate the SE performance of multiple layers of these materials. Figure 3.6 shows the SE/dBm of the RC vehicle when covered in 2 layers of conductive fabric tape, 2 layers of Aluminium tape and a combination layer which comprises 1 layer of conductive fabric tape plus 1 layer of Aluminium tape. It turned out that a double layer of Aluminium tape provided the highest SE.

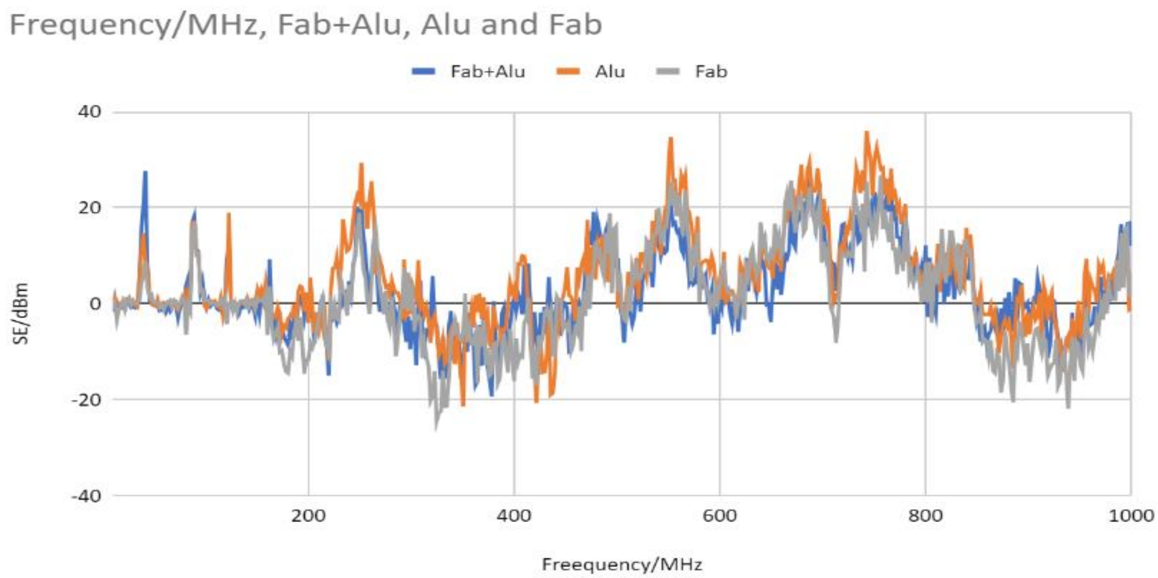

Figure 3.6 Graph of SE/dBm against Frequency/MHz for 2 layers of Aluminium Tape and Conductive Fabric Tape and 1 layer of each

Shielding method

Figure 3.7 shows the SE for the different shielding approach. This comparison was done using the Conductive Fabric Tape.

It can be seen that shielding the whole PCB box (in blue) resulted in a higher SE when compared to just shielding of the individual components (in orange). However, shielding the whole PCB will increase the overall weight due to the additional 3D printed box encapsulation.

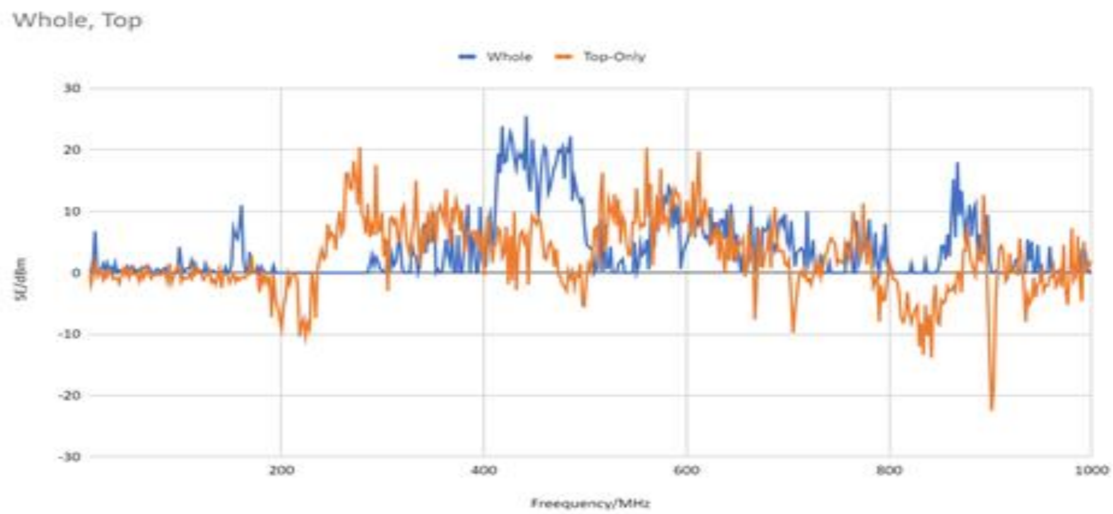

Figure 3.7 Graph of SE/dBm against Frequency/MHz for Shielding the Whole PCB and only certain parts of it

Comparison of weight on implemented solution

Additional weight to the RC vehicle is a crucial factor as it may impact performance such as reducing battery life or life-time of the motors. The corresponding weight of the RC vehicle for each shielding method is tabulated in Table 3.10. As shown, shielding only the IC chips has the least weight increase. This solution only contributed 4g to the total weight and from Figure 3.7, the highest SE that can be achieved is 20dB when tested with the Conductive Fabric Tape. This SE can potentially be 5dB higher if implemented with Aluminium Tape. However, to increase the susceptibility level of the RC vehicle, 2 layers of Aluminium Tape over the whole PCB is recommended as it can offer up to 36.06dB at 742.6MHz. The effective increase in weight for the 2 layers of Aluminium Tape is 8g but due to the 3D printed box, the net weight increase is 47g. Further research can be conducted to reduce the weight of the 3D printed box.

Set-up/shielding part	**Mass/g**
Original RC vehicle	453
3D printed box	39
3D printed box with 2 layers of Aluminium Tape	500
3D printed box with 2 layers of Conductive Fabric Tape	503
3D printed box with 1 layer of Conductive Fabric tape and 1 layer of Aluminium tape	502
Only Shielding IC Chips of PCB using Conductive Fabric Tape (Without 3D printed box)	457

Table 3.10

Discussion

Based on our results, the combination of 2 layers of aluminium tape give the highest shielding effectiveness. These materials are light, thin and highly malleable and hence, can be shaped into the required shapes easily. They are also relatively cheap and can be obtained easily and as such, are prime materials for short-term shielding or for shielding in commercial use. However, conductive fabric tape, while still being cheaper than many current solutions, is significantly more expensive than aluminium tape and as such, depending on the application, aluminium tape might be preferred. Shielding all the components fully also is much more effective than only shielding some components but at the expense of weight increase.

However, the effectiveness of these materials and methods might vary from frequency to frequency and more extensive testing will be required for higher frequencies. Moreover, the application of the device will also determine the choice of materials and shielding methodology. For example, shielding an Unmanned Aerial Vehicle (UAV) would require much more lightweight solutions as compared to a RC vehicle on ground.

For wire grounding, larger devices with higher current flowing through the wires would induce a significant current in the wire shields causing a much less effective shielding. As such, a grounding plate might be necessary for these wire shields. This grounding plate could be the chassis of the device if it is a mobile device, or the ground itself for a static device.

For much more complicated PCBs with many wires coming out from it, shielding individual components could prove to be more effective due to the numerous apertures produced by the wires exiting the box holding the PCB. Furthermore, for devices that require much more lightweight solutions, covering only some portions of the PCB would be more desirable. However, this would come at a significant impact of a reduced EM shielding effectiveness.

The results of our experiments have many practical applications. Aircrafts and UAVs often require signals to be transmitted and also some level of shielding to prevent external sources from interfering with their performance. These also have an application in defence purposes to reduce the effectiveness of malicious attacks via EMPs and other such harmful EM radiation.

In future experiments, more research could be done on finding ways to incorporate these shields into the components themselves to reduce the amount of space that the EM shields require. Research could also be carried out to develop a material that is able to incorporate the properties of both the Aluminium Tape and the Conductive Fabric Tape to effectively provide a good shield at both high and low frequencies simultaneously.

Acknowledgments

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