Investigation of Shielding Materials, for the Purpose of Shielding Electromagnetic Fields

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Abstract: This paper deals with an investigation of the shielding effectiveness of shielding material HSF 54 and windows foil Profilon Antyspy. The motivation for this research was the ongoing need in the field, for improvement of shielding properties against electromagnetic fields. It is focused on the frequency range 0.8-9 GHz. Measurements were performed according to the IEEE 299-2006 Standard. The shielding coating was applied directly, on the MDF board, then measurements of shielding effectiveness and reflection of for all samples were performed in an anechoic chamber. The attenuation of the investigated samples was calculated from the measured values. Subsequently, the presence of spatial charge on the examined samples were measured in the anechoic chamber. It was found that all materials have shielding ability, to prevent the penetration of an electromagnetic field. The presence of spatial charge varies depending on the frequency of the electromagnetic field and its duration. It can be stated that it is necessary to ground each shielding coating, in order to avoid injury or destruction of electronic equipment.

Keywords: electromagnetic wave; frequency; absorption; reflection; shielding, spatial charge

1 Introduction

In the past, electromagnetic radiation was an unknown topic for the lay public. With the dramatic increase of wireless technologies (mobile phones, Wi-Fi Internet, etc.), even the lay public is becoming increasingly interested in the issue. Mobile transmitters are placed on residential buildings, which can pose a threat from a possible radiation source. Currently, there are several options to protect against radiation from electrical equipment.

Limiting electromagnetic radiation is already possible during the design of electrical equipment. The manufacturer of the device must to comply with standards for the emission of electromagnetic radiation. However, it is not possible to completely eliminate electromagnetic radiation. On the other hand, for the operation of mobile devices, it is not desirable that the signal be eliminated. In that case, the only way to prevent electromagnetic radiation is to use shielding. There are many studies in the world that focus on the health problems caused by excessive exposure to the electromagnetic field.

It is necessary to realize that a person is constantly exposed to an electromagnetic field. Up to 80% of a person's time is spent inside buildings - at work, at home while shopping, etc. Therefore, buildings can offer a natural shielding of materials against the effects of the electromagnetic field. In our papers [1-5] we investigated the shielding effectiveness of commonly available building materials. We investigated that even common building materials have a shielding ability. In the case of the polystyrene material, the shielding ability is minimal to none. In the case of brick, we observed the shielding effectiveness in the frequency range from 1 GHz to 9 GHz. It is also true that with the increasing thickness of the shielding material, the shielding ability of the material increases. The shielding ability of the material is defined by the shielding effectiveness *SE*. If it is necessary to increase the shielding effectiveness, it is possible to do the following:

a) Change the thickness of the material - it is unrealistic for buildings

b) Add additional material, for example, shielding coating, foil, etc.

c) In this article, we focus on the use of a shielding coating and the use of a shielding foil.

2 Shielding Effectiveness of the Electromagnetic Field

The shielding ability of the material can be defined by the shielding effectiveness of the electromagnetic field. Shielding effectiveness can be determined in two ways:

a) According to IEEE 299-2006 Standard, Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures based on the measurement of shielding effectiveness. This measurement was performed in an anechoic chamber. The measurement consists of two steps – with and without shielding, and based on the difference between these values, we calculate the shielding effectiveness of the shielding. The IEEE Standard determines the calculation of the shielding effectiveness based on parameters - electric field intensity, magnetic field intensity, electromagnetic field power and electromagnetic field voltage.

b) The shielding effectiveness can be calculated based on the relation (1), where A is the absorption of the electromagnetic field and R is the reflection of the electromagnetic field. If we know the parameters A and R, then the effectiveness of the shielding of the electromagnetic field is given by the sum of absorption and reflection of the electromagnetic field. The following figure (Fig.1) shows how the electromagnetic wave penetrates through the shielding material. It can be seen that part of the wave is reflected, part of the wave is absorbed by the shielding material and part of the wave passes through the material in the form of a transmitted wave. In practice, however, it is difficult to measure the absorption of the electromagnetic field because the absorption occurs inside the material. Therefore, the absorption of the electromagnetic field can be calculated from the shielding effectiveness and the reflection of the electromagnetic field. The SE and R parameters can be measured in an anechoic chamber based on the IEEE standard.

In this paper, we focused on the research of the shielding effectiveness of electromagnetic field and reflection for the above-mentioned shielding foils and coatings. In our measurements, the values of the electromagnetic field intensity were in dB, therefore the equation (2) was used to calculate the shielding effectiveness

$$SE=A+R \tag{1}$$

$$SE=P_1+P_2 \tag{2}$$

where P_1 is the power of the electromagnetic field hitting on the shielding material and P_2 is the power of the electromagnetic field behind the shielding material.

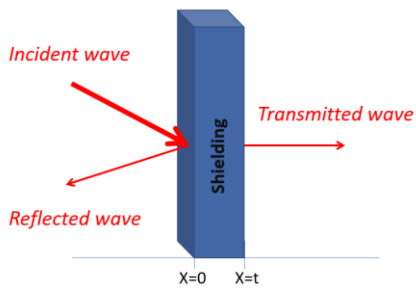

Figure 1

Propagation of the electromagnetic wave through the shielding material.

The second part of article was focused on the investigation of the formation of spatial charge on the examined samples.

3 Shielding Effectiveness Measuring Setup

As mentioned earlier, in this paper, we focus our research on the shielding effectiveness of electromagnetic fields, using different shielding materials. Three materials were used:

a) Shielding material HSF 54

b) Shielding foil 1 – for commercial use (Profilon Antyspy)

c) Shielding foil 2 – for commercial use (Profilon Antyspy)
HSF 54 shielding coating is a universal electrically conductive coating used to shield low and high frequency electromagnetic radiation. It composed on the basis of carbon and high-quality acrylic binder. It is frost-resistant and this makes it a widely applicable coating for both interiors and exteriors. PROFILON AntiSpy window foil is a special security type of foil designed to block RF, IR, UV and solar energy. In addition, it is also intended for protection against electromagnetic interference (EMI). It is installed on the buildings or on window. According to the technical sheet, the shielding effectiveness of this foil ranges up to 33 dB (AS100) and up to 46 dB (AS260). During the measurement, we marked this foil as foil 1. We marked the second foil as foil 2.

The set of the measuring workplace consists of a receiving antenna, transmitting antenna, pulse generator and a spectrum analyzer. In the first step, the workplace was calibrated based on the telecommunications equation:

$$P_P = P_V - L_0 + G_V + G_P \tag{3}$$

where P_P is the received power, P_V is the transmitted power, L_0 is the free space losses, G_V is the gain of the transmitting antenna and G_P is the gain of the receiving antenna [6-8].

The principal view of the arrangement of antennas is shown in Fig. 2. However, no shielding was placed between the antennas during calibration. We placed the receiving and transmitting antenna at a distance of 2 m from each other at the same height from the floor and turned the antennas as precisely as possible perpendicular to each other. After the successful calibration, we placed the shielding material - a wooden board and the shielding effectiveness was measured. The shielding effectiveness values were considered as reference values. This is because the coating and foils were placed on a wooden board. If the measurement without shielding was considered as the reference value, then the shielding effectiveness value of the wooden board would be included in the shielding effectiveness. Therefore, the values of the shielding effectiveness of the wooden board were subtracted from the values of the shielding effectiveness of the shielding materials. The measurement was performed in the frequency range from 0.8 GHz to 9 GHz with a step of 0.01 GHz.

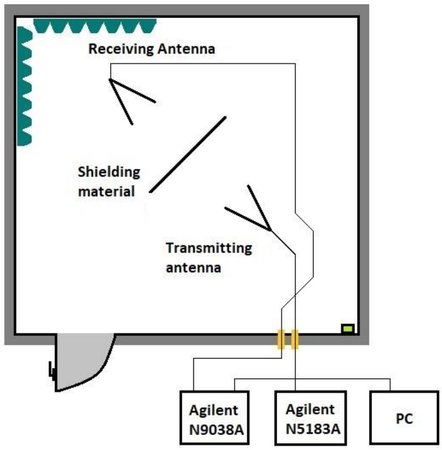

Figure 2
Experiment setup for measuring shielding effectiveness of electromagnetic field

When measuring the reflection of the electromagnetic field, the arrangement of the antennas inside the chamber is shown in Fig. 3. The arrangement was performed so that the antennas did not interfere with each other.

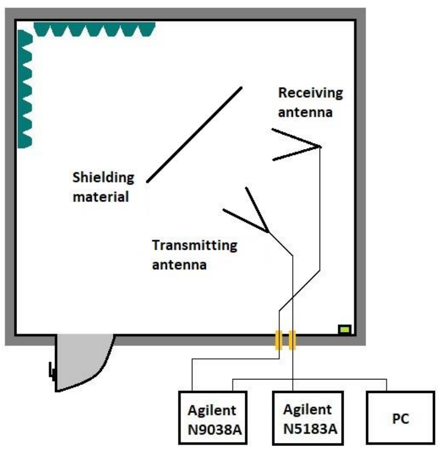

Figure 3
Experiment setup for measuring reflection of electromagnetic field

4 Experimental Results

a) **Shielding Effectiveness**

As mentioned earlier, the measurement of shielding effectiveness is a comparative method where we compare the measurement without shielding and with shielding. After subtracting these two values, we have the value of the shielding effectiveness in the investigated frequency range.

Figure 4 shows the dependence of electromagnetic field shielding effectiveness for three shielding materials – shielding coating HSF 54, shielding foil 1 and shielding foil 2.

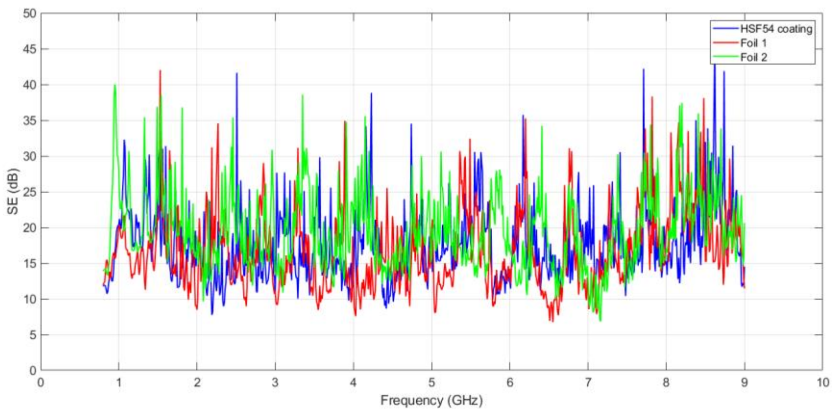

Figure 4
Shielding effectiveness in the frequency range from 0.9 GHz to 9 GHz

From the results, a similar shielding effect can be observed for all three shielding materials. The material "Foil 1" have the lowest values. The shielding effectiveness in the investigated frequency range reaches values from 10 dB to 30 dB. We do not observe a rising or falling trend in the monitored frequency range. All three shielding materials have approximately the same values in the whole measured range. In the research that we published in [1-5] the same was true for the material polystyrene. Also, no trend was observed. However, an increasing trend was observed in the investigated frequency range for the brick material. In addition, the shielding effectiveness reached low values in the first third of the observed frequency range. The highest shielding effectiveness values were achieved in the last third of the observed frequency range. However, for measuring of shielding effectiveness - HSF 54 shielding coating, shielding foil 1 and shielding foil 2 - this fact was not confirmed. It follows that all three materials are suitable for shielding the investigated frequency range and have a similar shielding effect.

b) Reflection of Electromagnetic Field

As mentioned in the section a), the shielding effectiveness does not reach a clear trend, but the values are defined in the range. However, this does not mean that the same applies to the reflection of the electromagnetic field. This is because the ratio of absorption and reflection can change in the monitored frequency range. This ratio can be change depending on the shielding material. However, it is still true that the sum of the reflection and absorption of the electromagnetic field is equal to the shielding effectiveness. In Fig. 5 it is possible to see the dependence of the reflection of the electromagnetic field in the observed frequency band from 0.9 GHz to 9 GHz.

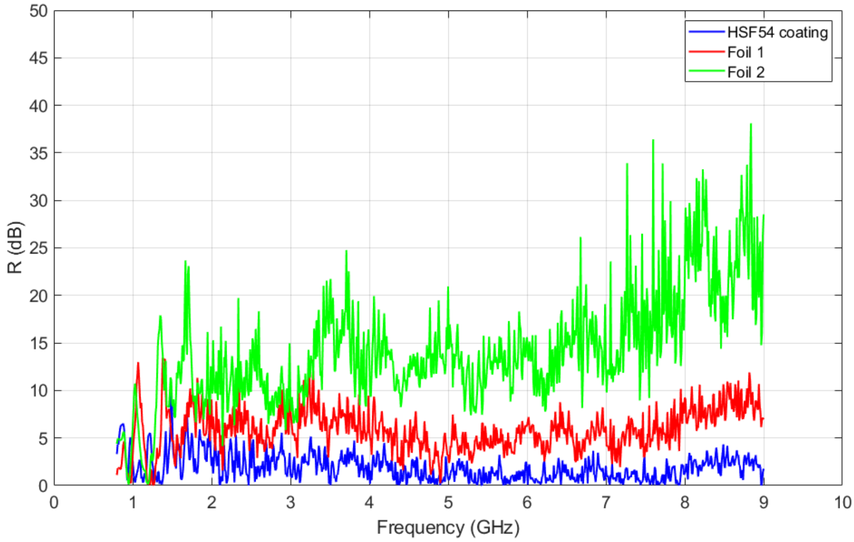

Figure 5
Reflection of electromagnetic field in the frequency range from 0.9 GHz to 9 GHz

From the results, it can be seen that the material Foil 2 achieves the highest values of electromagnetic field reflection. The material HSF 54 achieves the lowest values. In the investigated frequency range, an increasing trend of electromagnetic field reflection can be observed.

In the case of HSF 54 material, no trend was observed and the values are within a narrow range. The maximum value of electromagnetic field reflection for HSF 54 material is approximately 5 dB. The results show that the absorption of the electromagnetic field represent a larger part of the shielding effectiveness. This material therefore, absorbs the electromagnetic field more than it reflects it.

In the case of the Foil 2 material, the situation is the opposite. As the frequency increases, so does the proportion of electromagnetic field reflection. With the frequency increasing, the proportion of absorption decreases.

c) **Measuring the Spatial Charge**

The issue regarding the formation of spatial charge on shielding materials is relatively new. Accumulation of spatial charge may be dangerous for sensitive electronic devices. The main motive of the investigation the spatial charge was whether it would occur on the samples and in what quantity.

The measurement time was set to 100 seconds, while the measurement took place in the following manner. At time t_0 = 0 s the measurement started, at time t_1 = 30 s the antenna, i.e., the source of the electromagnetic field, was turned off, and the measurement of the spatial charge continued. The results were recorded by a computer connected to the measuring device. Subsequently, the voltage values were read at the respective times t_1 = 30 s, t_2= 60 s and t_3=90 s.

The workplace for spatial charge measurement is shown in Fig. 6. The Trek 541 A device was used for the measurement, with a measuring range from -1 kV to +1 kV. The measuring probe with high sensitivity is placed closest to the measured object at a distance of 2.5 mm – 1 mm. During the measurement, the transmitting antenna was placed at a distance of 1 m from the measured sample. The following figure 6, shows the wiring diagram.

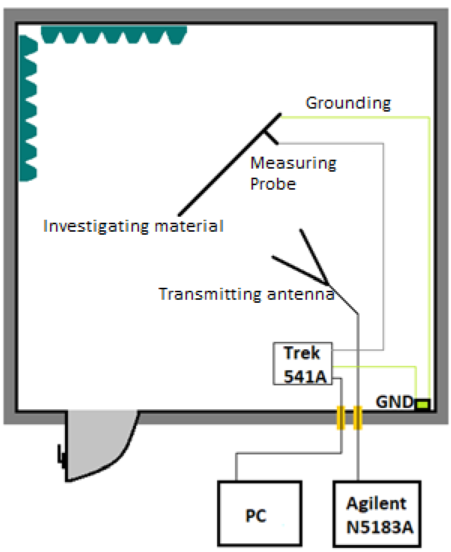

Figure 6
Experiment setup for measuring the spatial charge

The spatial charge measurement was performed with a grounded and ungrounded sample. Since the measured value was 0V when measuring with a grounded plate, the results will not be presented in the tables.

First sample on which the voltage of spatial charge was measured was a MDF board painted with professional paint YShield HSF 54. With an ungrounded plate, the value of the spatial charge voltage increased together with increasing frequency. The decrease in value occurred at the 7.4 GHz frequency. At frequencies of 8.6 GHz, the value increased sharply and reached the maximum value achieved with this sample. The charge had a positive polarity during the entire measurement at all frequencies.

Table 1

Values of measured spatial charge for a MDF board with HSF 54 shielding paint

	Ungrounded plate		
	Voltage of the spatial charge U [V]		
f [GHz]	t1 = 30s	t2 = 60s	t3 = 90s
0.9	5.5	5.5	6
2.1	6	5.5	6
2.6	5.5	5.5	6
3.8	6	6.5	6.5
5	7.5	7	7
6.2	7	7.5	6.5
7.4	3	7	6
8.6	12	11.5	13.5

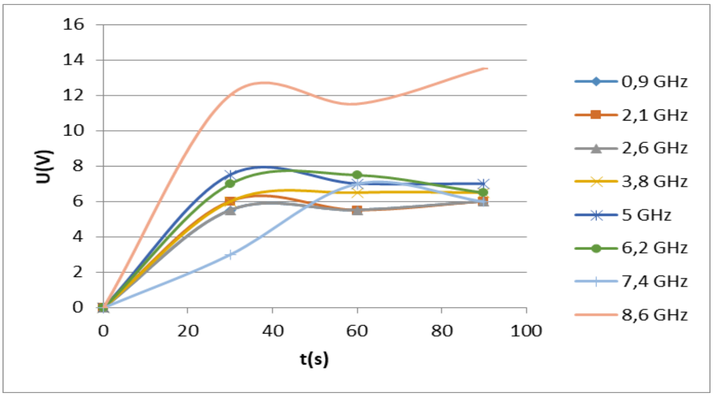

Figure 7

Dependence of spatial charge voltage on an ungrounded MDF board with HSF 54 shielding paint

The sample shielding foil 1 at the initial frequency of 900 MHz reached negative values of the spatial charge at all measured times in the range from -21V to -4.5V.

As the frequency increased to 2.1 Ghz, there was a sharp increase and subsequent pre-polarization. By gradually increasing the frequency, the spatial charge remained approximately the same, and the change occurred at a frequency of 6.2 GHz, when the charge increased slightly, until the frequency increased to 8.6 GHz, when the charge decreased again. Graphically, this course is shown on the Figure 8.

Table 2
Values of measured spatial charge for a shielding foil 1

	Ungrounded plate		
	Voltage of the spatial charge U [V]		
f [GHz]	t1 = 30s	t2 = 60s	t3 = 90s
0.9	-24.5	-23	-21
2.1	3	1	1.5
2.6	0	3	1
3.8	1.5	1	1
5	1.5	3.5	2
6.2	4.5	5.5	7
7.4	6	7	6.5
8.6	2.5	2	3

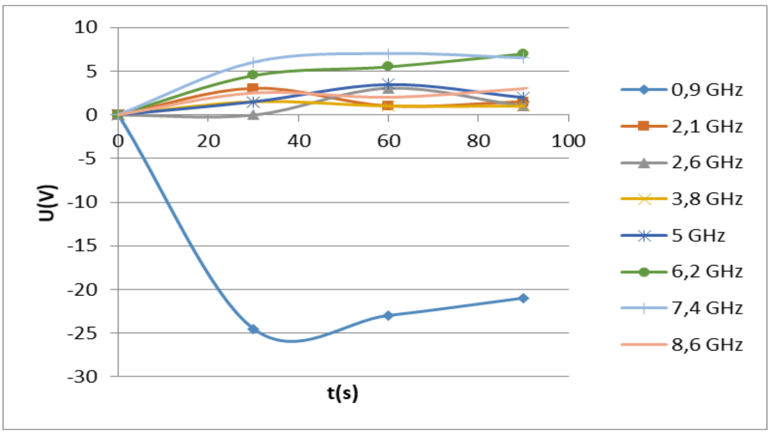

Figure 8
Dependence of spatial charge voltage on an ungrounded shielding foil 1

The following table shows the results for a shielding foil 2.

Table 3

Values of measured spatial charge for a shielding foil 2

	Ungrounded plate		
	Voltage of the spatial charge U [V]		
f [GHz]	t1 = 30s	t2 = 60s	t3 = 90s
0.9	-2.5	-0.5	-0.5
2.1	-1	-1	-1
2.6	-8	-10	-11.5
3.8	-11	-11	-13.5
5	-11.5	-12	-11.5
6.2	-9.5	-10.5	-11.5
7.4	-9	-11.5	-11.5
8.6	-10	-11.5	-10.5

Shielding foil 2 reached negative voltage values, which increased even after the antenna was turned off. The highest value of the voltage was at the frequency of 3.8 GHz at the time of 90 s, when 60 s had passed since the antenna was turned off. The change occurs at the frequency of 2.6 GHz at which the value of the charge increased, and from this value the space charge did not change much by changing the frequency.

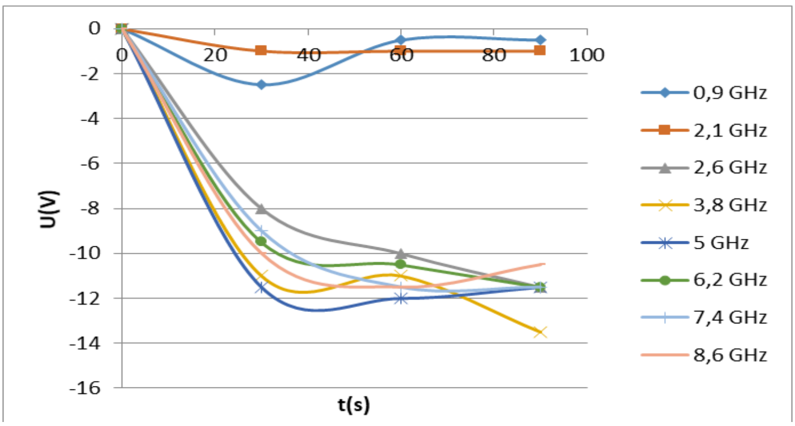

Figure 9

Dependence of spatial charge voltage on an ungrounded shielding foil 2

Conclusions

This paper is focused on examining shielding effectiveness, measuring and reflection of electromagnetic fields. Shielding effectiveness consists of reflection and absorption of the electromagnetic field. If we know shielding effectiveness and reflection of the electromagnetic field, it is possible to calculate the absorption of the electromagnetic field. The measurements were performed in an anechoic chamber, within the frequency range of 0.9 GHz to 9 GHz. Each measurement was repeated 3 times, in order to increase accuracy. Based on the measurements, it is possible to evaluate the research:

a) By measuring the effectiveness of the shielding, it was found that all three materials have the shielding ability to prevent the penetration of the electromagnetic field. No of increase or decrease trend in shielding effectiveness values was observed. The values are defined in range from 10 dB to 30 dB.

b) By measuring the reflection of the electromagnetic field, the situation is different. The material Foil 2 achieves the highest values of electromagnetic field reflection. The material HSF 54 achieves the lowest values. In the investigated frequency range, an increasing trend of electromagnetic field reflection can be observed. In the case of HSF 54 and Foil 1 material, no value trend was observed.

c) The material HSF 54 achieves the lowest values of reflection of the electromagnetic field. It follows that this material achieves high values of absorption and is therefore suitable for absorbing the electromagnetic field. The same applies to foil 1. In the case of foil 2, the electromagnetic field reflection values also increase with increasing frequency. It follows that the absorption of the electromagnetic field decreases with increasing frequency.

d) HSF 54 material is more suitable for absorbing the electromagnetic field. Foil 1 is also suitable for electromagnetic field absorption. In the case of foil 2, the absorption of the electromagnetic field decreases with increasing frequency, and at the same time the reflection of the electromagnetic field increases.

This research shows how to wisely choose shielding materials, in building planning and practice. There are cases when the reflection of the electromagnetic field is undesirable. In this case, the material HSF 54, is a suitable shielding for these purposes.

The second part of this work was focused on the measurement possibilities for the creation the spatial charge. Accumulation of spatial charge may be dangerous for sensitive electronic devices. Spatial charge was detected on all ungrounded samples under the influence of a high-frequency electromagnetic field. The presence of charge varies, depending on the frequency of the electromagnetic field and its duration. It can be stated that it is necessary to ground each shielding coating, in order to avoid injuries or the destruction of electronic equipment.

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