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Cellular tubular structures from perforated metallic tape and its application

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Abstract. The objectives of performed research were the following: 1) check out the possibility of effective formation of the tubular and planar structures from the perforated steel tapes, which were obtained as a waste during stamping of fine-sized details, by cutting and bending; 2) testing of achieved tubular and annular structures for fixing up of the electrical cables and as electromagnetic shielding solutions; 3) analysis of achieved results and elaboration of the recommendations for using of lightweight tubular shields for the electrical cables. The actuality of research is connected with the re-using of metallic wastes and shielding solutions against electromagnetic fields. All objectives were reached successfully using bending for formation of the tubular structures. The bending strength of achieved structures and the shielding efficiency in a controlled environment was examined. The measurement results have shown that perforated steel will exhibit noticeable shielding properties against both the electric and magnetic field. Such results open up wide possible application of the planar and cellular tubular structures from perforated metallic tapes.

Key words: perforated metallic waste, tubular structures, electromagnetic fields, shielding.

INTRODUCTION

During last years the perforated metallic materials (PMM) become more used in building industry and mechanical engineering. For example, such materials are widely used as spacers for wall and floor constructions, for containing walls or sandwich wall structures (Lisicins et al., 2015). Another popular application of PMM is using as reinforcement material in concrete works and brickworks (Kalva, 2011), as well as fixtures and connectors for nodes of wooden constructions (Ozola, 2011). The support structures consisting of an annular or tubular casing, which cavity is arranged with reinforcing member and filled with the infill material were proposed by Mironovs & Lisicins (2015). Due to light weight and decorative behaviour PMM also used for producing the elements of ventilation devices, filters, channels and heating systems. In such applications the tubular structures are usually used (Perforated metal, 2016). Also

PMM have been actively used in the construction of cladding panels in residential housing or as so called thermoprofiles (Garifullin et al., 2015).

Nowadays it is possible to produce the tubular structures from the PMM in wide diapason of the diameters (from few mm to one and more meters) with length up to 10 meters and larger according to application (Wadley et al., 2003; Perforated metal, 2016). The choice of manufacturing method for producing tubular structures from PMM is based on the tube diameter and length, material thickness, mechanical properties of the material etc. Mostly the welded tubular structures are used, which were produced from the PMM tape by spiral twisting, winding, stretching and profiling (Wadley et al., 2003; Wadley, 2006; Mironovs et al., 2013).

Mironovs et al. (2014) have shown the possibility of application of cellular structures from perforated metallic tape for electromagnetic solutions, in particular shields for electrical cables (Fig. 1). It should be mentioned, that it is necessary to analyze the mechanical properties of PMM and achieved structures using appropriate simulation and/or experimental evaluation methods (Ochsner et al., 2001; Vaz et al., 2011; Bhavitha et al., 2015).

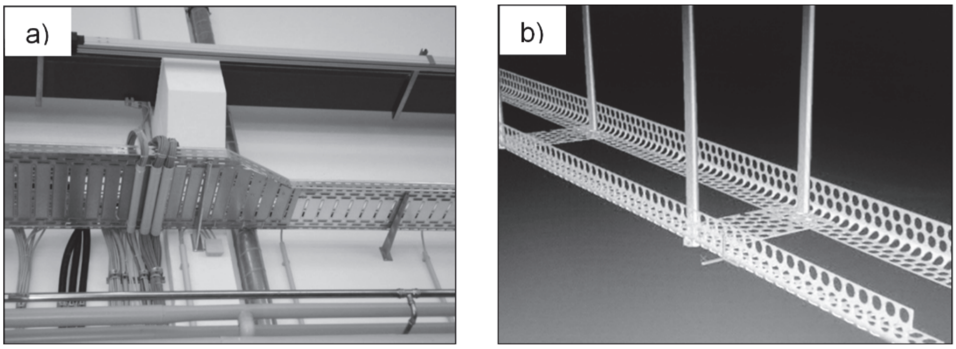


Figure 1. Application of cellular structures from MPP for placing of suspended cables in closed construction (a) and open construction (b).

Mostly for manufacturing cellular structures the specially produced PMM are used. More effective way is to use the perforated steel tapes, which are obtained as a waste during stamping of fine-sized details, for example, elements of the leaf chain (Mironovs et al., 2014). Since the base material usually is the structural steel with relative high carbon content such metallic waste is characterized by high strength.

The main objective of performed research was the testing of tubular and annular structures achieved by bending for fixing up of the electrical cables and as electromagnetic shielding solutions. The actuality of research is connected with the re-using of metallic wastes and shielding solutions against electromagnetic fields.

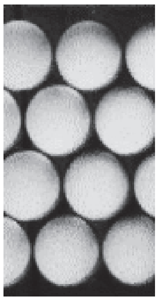
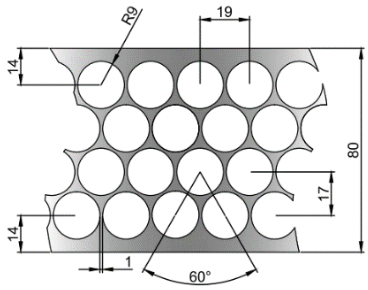
The necessity of shielding electromagnetic fields may be presented in many forms (Borner et al., 2011; Koppel et al., 2013). In telecommunications shielding devices and cables is aimed at preventing crosstalk and interference from a device to another. Such interference or crosstalk may emanate from the cables that carry some sort of communication signal. Even cables that just pass on a significant amount of the electrical current may affect sensitive nearby electronic devices. In such case a shielding of the cables is sought for.

In this paper electromagnetic field measurements were conducted to determine the shielding effectiveness of perforated steel elements placed around or next to the power cables that irradiate extremely low frequency (power frequency 50 Hz) magnetic and electric fields.

MATERIALS AND METHODS

Usually, the cable packages at a great length have a significant weight. Therefore in case of placing those into suspended perforated metallic constructions under ceilings the mechanical properties (especially bending strength) of perforated tubes are of great importance. Mechanical and geometrical parameters of PST-2 type perforated steel tape (trade mark of JSC 'DITTON Driving Chain Factory', Latvia), which was used for producing of perforated steel tubes for supporting and shielding of the cable packages are shown in Table 1. This tape is achieved as a technological waste during stamping of the elements of driving chains which are used in motor industry.

Table 1. Mechanical and geometrical parameters of PST-2 type perforated steel tape, which was used for producing of perforated steel tubes for supporting and shielding of the cable packages.

Parameter	Value	Tape representation	Tape geometry
designation	PST-2		
mark of steel	08пс-ОМ-Т-2-К		
standard	GOST 503-81		
thickness, mm	1.50		
width, mm	80		
permeable area, %	69.10		
effective cross-sectional area, mm^2	25.13		
tensile load bearing capacity, kN	5.54		
tensile strength, MPa	220.65		
displacement, mm	6.54		
strain, %	3.93		

For research the samples of cellular tubular structures (tubes) with diameter 27 mm and length 1 m were produced by bending. View of the perforated steel tube is shown on Fig. 2, but the three-point bending testing process of the perforated steel tube is shown on Fig. 3. The span between supports was 350 mm. Loadings rate was 30 mm/min, air temperature: +24 °C. The loading was performed by Instron 10000 (Instron, USA) testing machine.

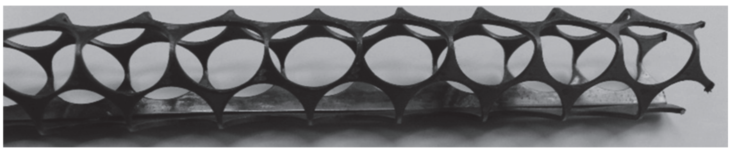


Figure 2. View of the perforated steel tube (fragment).

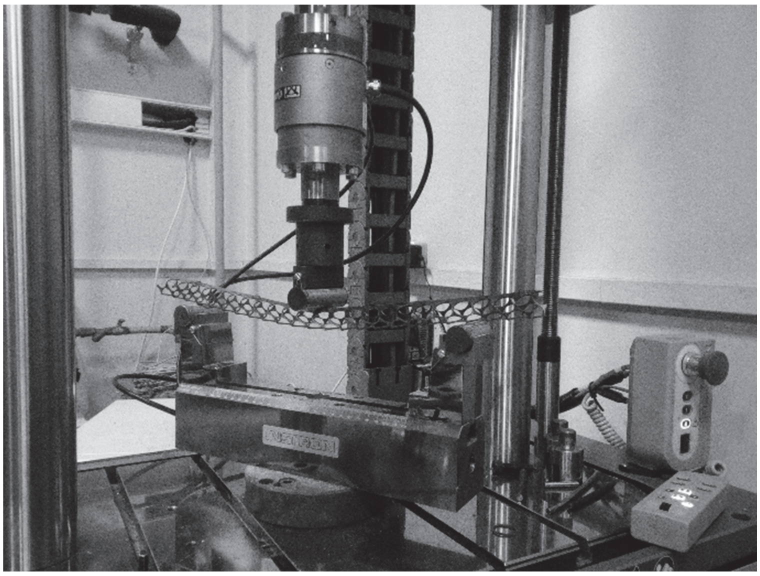


Figure 3. Testing process of perforated steel tube made by Instron 10000 testing machine.

Fig. 4. shows the relationship between flexural stress and strain of perforated steel tube made of material described in Table 1. As shown three-point bending testing proves the possibility to use such tubular structures for fixing up of the electrical cables and cable packages.

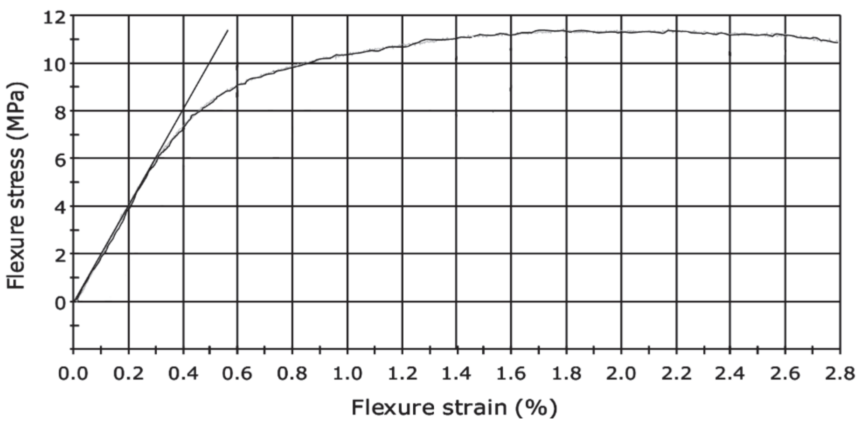


Figure 4. The relationship between flexure stress and flexure strain of perforated steel tube, the straight line reflects the modulus of elasticity in shear.

In order to test the shielding effectiveness of perforated steel structures against electromagnetic field, two forms of samples were produced: 1) a tube as was mentioned above and 2) a planar strip. Both were of a length of one meter. Power cables were positioned in the center of the tubular sample and in the center of the side of the planar sample (Figs 5, 6).

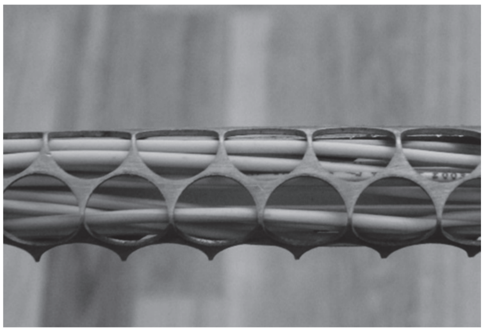


Figure 5. Perforated steel tube shielding with the power cable package.

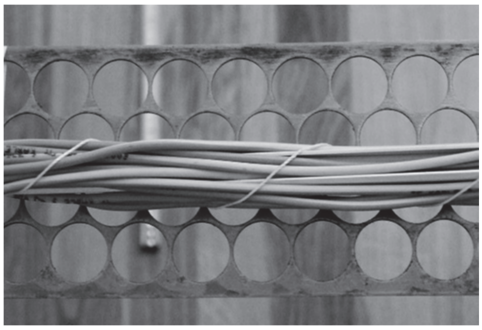


Figure 6. Perforated steel strip sheet shielding with the power cable package.

A high current was run through 14 isolated copper cables (1.5 mm^2). When an electromagnetic field hits another material than the one it travels within, some of the energy may be reflected and the rest transmitted through. In this study the effectiveness of the shielding intervention is determined by measuring the electromagnetic field before and after the intervention. The shielding articles are meant for power cables meaning the frequency of 50 Hz.

The measurement device used was Gigahertz Solutions NFA400 (Langenzenn, Germany). In order to guarantee the reliability of the measurement results the area was constantly monitored for background electromagnetic fields, which topped at 9 nT (nanoTeslas) for magnetic field and 5 V m^{-1} (Volts per meter) for electric field. It was also controlled that no other electromagnetic field sources were nearby that would affect the reading.

The cables were positioned horizontally to the height of 1 m from the floor. The measurement readings were taken from the same height at 12 different distances from the cable: starting from 0.05 and ending with 2.5 m. The range of interventions applied included (Fig. 7): A) unshielded wire bundle, B) application of tubular shield, C) application of grounded tubular shield, D) application of planar shield, E) application of grounded tubular shield. In case of magnetic field, the shielding of course makes no difference, measurements were conducted only for the scenarios A, B and D.

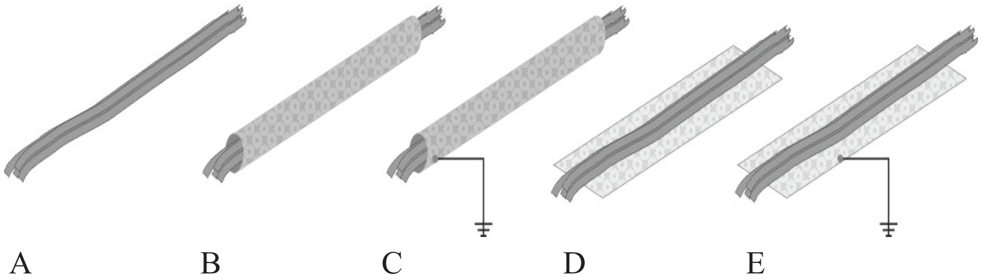


Figure 7. The investigated electromagnetic irradiation scenarios: A) unshielded wire bundle, B) application of tubular shield, C) application of grounded tubular shield, D) application of planar shield, E) application of grounded tubular shield.

In order to conduct measurements one must note the different field propagation principles of electric and magnetic fields. In Fig. 8 the propagation path is pictured by arrows. Whereas electric shielding is easier to achieve due to straightforward path of the electric field lines. The magnetic field lines always need to finish the loop, making encapsulating this more complex task.

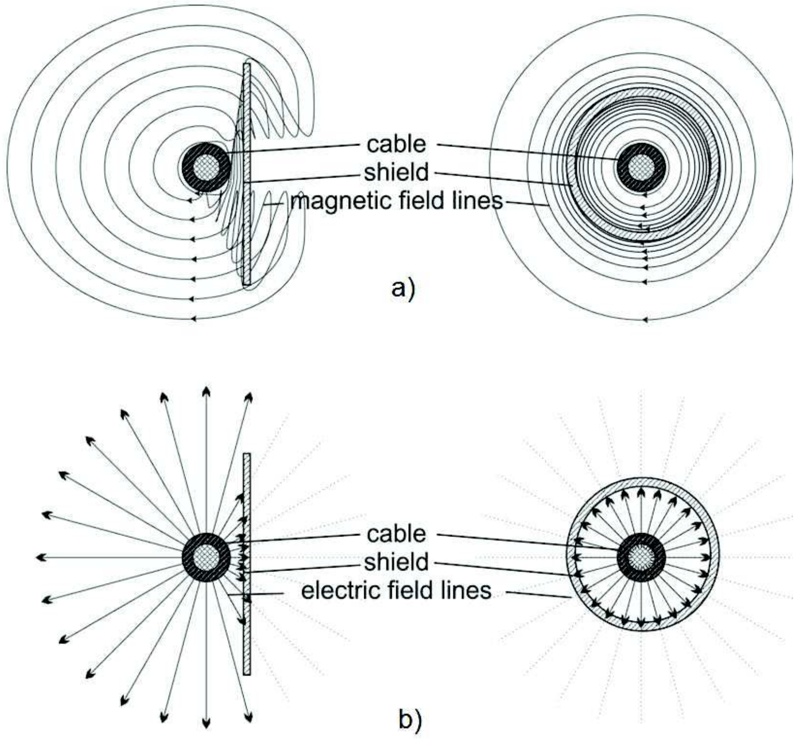


Figure 8. A principal field propagation of magnetic (a) and electric (b) field in respect to the planar and tubular shielding measures.

RESULTS AND DISCUSSION

For the electric field, the measurements clearly indicate the importance of grounding the shield. Without the grounding, at 0.5 m the 100% of the planar shield and 78% of the tubular shield electric field passed through. While grounding the shield, at 0.5 m the transmission of the electric field was retained at 28% for the planar shield and 30% for the tubular shield (Fig. 9 and Table 2).

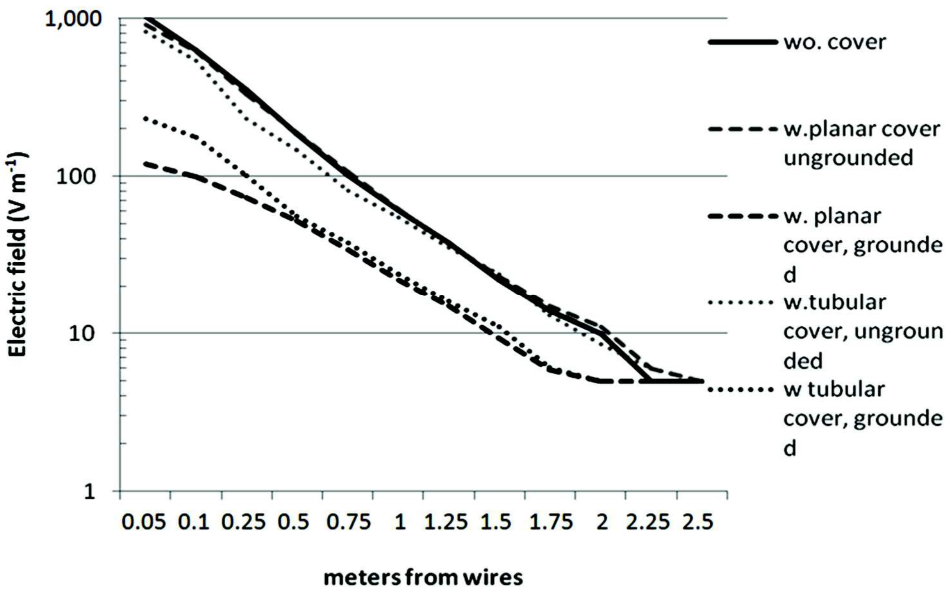


Figure 9. Electric field strength for a wire bundle with (w.) and without (wo.) a perforated steel cover.

Table 2. Electric field strength (V/m) for a wire bundle with and without a perforated steel cover: A) unshielded wire bundle, B) application of tubular shield, C) application of grounded tubular shield, D) application of planar shield (see Fig. 7)

Distance from the wires, m	A	B	C	D	E
0.05	1,016	906	120	821	230
0.1	628	614	99	536	175
0.25	354	326	73	231	101
0.5	185	187	52	145	56
0.75	100	105	34	81	38
1	61	62	22	55	24
1.25	38	37	15	35	16
1.5	22	23	9.3	24	11
1.75	14	15	5.9	13	6.1
2	10	11	5	8.5	5
2.25	5	6	5	6	5
2.5	5	5	5	5	5

In case of magnetic field the shielding effectiveness was less than compared to the electric field attenuation. At 0.5 m distance 74% of the magnetic field passed through the planar shield and 78% from the tubular shield (Fig. 10 and Table 3). In average the transmission across all measurement distances was 77% for the planar shield and 67% for the tubular shield.

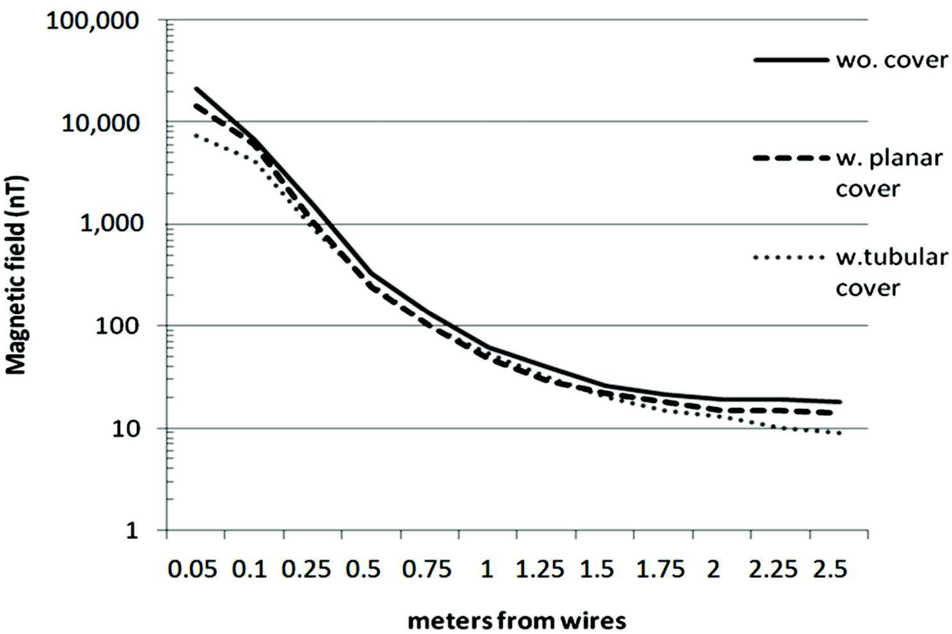


Figure 10. Magnetic field flux density for a wire bundle with (w.) and without (wo.) a perforated steel cover.

Table 3. Magnetic field flux density for a wire bundle with and without a perforated steel cover: A) unshielded wire bundle, B) application of tubular shield, D) application of planar shield (see Fig. 7)

Distance from the wires, m	A	D	B
0.05	21,300	14,290	7,346
0.1	6,857	6,050	4,194
0.25	1,540	1,021	892
0.5	332	245	260
0.75	130	98	100
1	61	48	54
1.25	39	29	32
1.5	26	22	20
1.75	21	18	15
2	19	15	13
2.25	19	15	10
2.5	18	14	9

The measurement results have shown that perforated steel will exhibit noticeable shielding properties against both the electric and magnetic field. Considering that the tested perforated shields are a manufacturing waste product, the surface of the shield is tightly packed with holes. In cases where only moderate shielding attenuation is required, the usage of the studied material may very well be justified. The application is likely to include cable pathways such us catwalks in the ceiling or inside the walls.

It should be mentioned that according to the information of the JSC 'Ditton Driving Chain Factory' (Latvia) only this enterprise produces about 500 tons of the perforated steel waste per year. The 'Ditton Driving Chain Factory' specializes in a wide range of roller-, bush-, leaf and other chains (Ditton Driving Chain Factory, 2016). Nowadays the waste obtained during cold stamping of the elements of driving chains of the motors is sold out as a metallic scrap in spite of the fact that the perforated tape is practically ready raw material that may be directed for processing without any significant preparation. That's why the recycling of such waste is actual and needed to be implemented.

Besides the noticeable shielding properties against both the electric and magnetic field the main advantage of the perforated steel tape is the smaller weight in comparison with the unperforated tape (0.21 kg against 0.29 kg of the 1 m of the tape). Such difference (28%) is significant taking into the mind the planned application of perforated steel tape for fixing up of the electrical cables and cable packages. At that the tensile strength of the perforated tape (220.65 MPa) is reduced only by 18% in comparison with the unnperforated conventional steel tape (270.00 MPa). Another important advantage is the lower cost of the perforated steel tape in comparison with the unperforated tape (0.041 EUR against 0.057 EUR of the 1 m of the tape) and decorative value of the perforated shield. These aspects as well as results of given research prove the economic and technological effect of the offered recycling of the perforated steel waste by application as shielding against electromagnetic field and fixing solution for the cables.

CONCLUSIONS

The new promising direction for recycling of the technological waste is offered. The plannar and tubular shields against electromagnetic fields were produced by cutting and bending from the perforated steel tapes, which were obtained as a waste during cold stamping of fine-sized details particularly elements of driving chains of the motors. Such manufacturing method not complicated, nor special equipment is needed, which together with waste as a base material allows to conclude that it is economically and technologically effectvie way to recycle the technological waste.

Achieved tubular and planar structures were tested for fixing up of the electrical cables and as electromagnetic shielding solutions. Bending test proves the possibility to use such structures for fixing up of the electrical cables and cable packages. From the other hand, testing of the shielding efficiency has shown that perforated steel will exhibit noticeable shielding properties against both the electric and magnetic field. It should be mentioned, that better results were achieved for the electric field shielding in the case of grounding the shield. Without the grounding, at 0.5 m the 100% of the planar shield and 78% of the tubular shield electric field passed through. While grounding the shield, at 0.5 m the transmission of the electric field was retained at 28% for the planar shield and 30% for the tubular shield.

Such results open up wide possible application of the cellular tubular and planar structures from perforated metallic tapes for fixing up of the electrical cable packages and as electromagnetic shielding solutions in cases where only moderate shielding attenuation is required. The application is likely to include cable pathways such us catwalks in the ceiling or inside the walls.

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