External Protection of Power Systems' Electronic Equipment from an Electromagnetic Pulse (EMP)

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Abstract: **External protection means protection of buildings and premises, where sensitive critical electronic equipment is located. This article discusses radioprotection features of conventional building materials (particularly concrete) and the impact of various factors on its protective features. The article also addresses composite materials with improved radioprotection features, and discusses their weaknesses. In particular, problems relating to their use in the electric power industry due to a large number of external cables running into the protected premises, and re-emitting an electromagnetic pulse into the interior of these premises. Radio-absorbing construction materials, i.e. those made of foam glass and ferrites are also discussed. As additional measures, the article suggests using enclosed and non-perforated metal cable trays in the interior of the protected premises, as well as architectural solutions for such premises. The article is intended to help a consumer in selecting the optimum option of external protection using his material and the technical capabilities in mind.**

Keywords: **EMP, HEMP, electronic equipment protection, radioprotected building materials.**

I. INTRODUCTION

As a rule, electronic equipment of power systems, such as digital protection relays (DPR), programmable logic controllers (PLC), automation systems, telecommunication, etc., is mounted in special control cabinets and connected to the grounding system. The cabinets are located in a control room (relay room), which is situated in the substation's building. The same "layer-based" principle should be applied to protection of this equipment from a devastating impact of an electromagnetic pulse of high altitude nuclear explosion (HEMP). Some of these "layers", for instance, electronic equipment's grounding systems; EMP filters installed in the inputs of this equipment; principles and means of control cabinets' protection, have been discussed elsewhere [1-3]. This article addresses the issues of protecting the substation's building and the control room, which is referred to here as "external protection'.

Why another "layer" – external protection – is necessary in addition to those "layers" discussed earlier? There are several reasons for this.

Firstly, it can be difficult to provide efficient HEMP protection with only one "layer". Sometimes it is even impossible, as HEMP represents both electric field in the air with a very high level (up to 50 kV/m at the ground surface) and a high voltage pulse applied directly to the input of the electronic equipment, and also a powerful interference at the grounding system, which penetrates directly to sensitive electronic elements, etc.

Secondly, individual electronic devices (DPR or PLC) are not insulated from another devices and systems at any facility in the electric power industry (such as a substation or power plant). They are connected to many other devices, which are often far away from each other. Thus, in this situation, efficient protection of each individual electronic device can be very expensive from a practical point of view, compared to "external protection" of the entire room, or even a building by using special construction materials.

The aim of this article is to discuss available options of providing HEMP protection for entire buildings or rooms and evaluation of efficiency of such protection.

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II. ANALYSIS OF CAPABILITY OF CONVENTIONAL BUILDING MATERIALS TO WEAKEN ELECTROMAGNETIC EMISSION

Practically significant experimental research of the capability of different construction materials to weaken the electromagnetic emission was conducted in the 1990s by The American National Institute of Standards and Technologies. In 1997 they published a full report with the findings of their research [4]. Unfortunately, the frequency range, which was used in their research, does not cover the real range of HEMP frequencies (100 kHz – 100 MHz). However, their findings (Table 1) are sufficient for general evaluation of the situation.

TABLE 1: EFFICIENCY OF ELECTROMAGNETIC EMISSION WEAKENING BY COMMON CONSTRUCTION MATERIALS

Building materials	**Attenuation, dB**	
	500 MHz	1 GHz
Concrete not rebar reinforced, thick:		
102 mm	7 – 11	11- 14
203 mm	17 – 25	22 – 28
305 mm	31 - 45	33 - 45
Reinforced concrete wall, thick 203 mm:		
rebar dia. 19 mm, dist. between rebars - 70 mm	26	30
rebar dia. 19 mm, dist. between rebars - 140 мм	23	27
Concrete blocks with hollow cavities, thick**:**		
203 mm	8	12
406 mm	13	17
609 mm	26	28
Regular dry lumber, diameter:		
38 mm	2	3
76 mm	1.5	3
152 mm	4.5	6
Bricks, thick:		
1 brick (89 mm)	0	3.5
2 bricks (178 mm)	3.5	5.5
3 bricks (267 mm)	4	7

TABLE 2: POWER ATTENUATION VALUE OF CONCRETE SAMPLES WITH VARYING MOISTURE CONTENTS

Attenuation, dB (ratio) for frequency	200 MHz	500 MHz	1 GHz
Moisture content, %			
0.2	3 (1.41)	4 (1.58)	4 (1.58)
5.5	11 (3.55)	18 (7.94)	20 (10)
12	18 (7.94)	32 (39.8)	35 (56.2)
Ratio of attenuation change for spot frequencies and different moisture content 0.2% to 12%	5.6	25.2	8.75
Average ratio of attenuation change by moisture content influence	13.2		

TABLE 3: REINFORCED CONCRETE WITH MESH INTERVAL OF 100 mm AND VARIOUS TYPES OF REBAR

Attenuation, dB (ratio) for frequency	100 MHz	200 MHz	500 MHz	1 GHz
Rebar diameter, mm				
10	25 (17.8)	20 (10)	12 (3.98)	5 (1.78)
30	40 (100)	35 (56.2)	30 (31.6)	20 (10)
50	70 (316)	60 (1000)	55 (562)	45 (178)
Ratio of attenuation change for spot frequencies and different rebar diameter 10 to 30 mm	18	100	141	100
Average ratio of attenuation change at rebar diameter influence	90			

TABLE 4: POWER ATTENUATION OF REINFORCED CONCRETE OF VARIOUS THICKNESSES WITH MESH INTERVAL OF 100 mm AND 20 mm REBAR

Attenuation, dB (ratio) for frequency	100 MHz	500 MHz	1 GHz
Concrete thick, mm 600 1000 1500	 60 (1000) 60 (1000) 60 (1000)	 25 (17.8) 30 (31.6) 40 (100)	 15 (5.62) 22 (12.6 30 (31.6)
Ratio of attenuation change for spot frequencies and different concrete thick 600 to 1500 мм	1	5.6	5.6
Average ratio of attenuation change at concrete thick change 600 to 1500 mm	4		

Reinforced concrete is expected to provide the best results, though the improvement (compared to non-reinforced concrete) is not as significant as expected (be reminded that 20 dB correspond to 10 times weakening of emission amplitude). Obviously, any changes of parameters of both concrete and its rebar (Fig. 1) can significantly impact the shielding quality of a building. How? This question is addressed in many research papers [5 - 8].

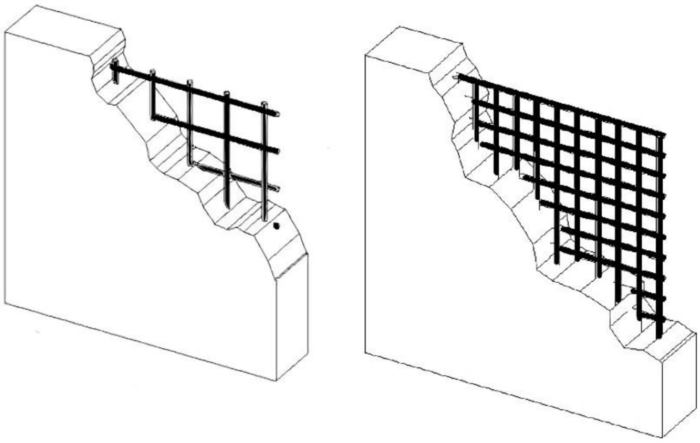

Fig 1: Reinforced concrete with various types of rebar

Tables 2 – 7 show some general data, which reflect the impact of changes in different parameters of the most common construction material on its shielding properties.

TABLE 5: POWER ATTENUATION OF 1000 mm THICK REINFORCED CONCRETE WITH 12% MOISTURE WITH ONE OR TWO LAYERS OF REBAR WITH MESH INTERVAL OF 100 mm AND REBAR DIAMETER OF 20 mm

Attenuation, dB (ratio) for frequency	100 MHz	500 MHz	1 GHz
1-layer rebar 2-layer rebar	70 (3160) 110 (316000)	55 (562) 65 (1780)	40 (100) 42 (126)
Ratio of attenuation change for spot frequencies at transition from 1-layer rebar to 2-layer rebar	100	3.2	1.26
Average ratio of attenuation change at transition from 1-layer rebar to 2-layer rebar	35		

TABLE 6: POWER ATTENUATION OF STRENGTHEN REINFORCED CONCRETE WITH VARYING DISTANCE BETWEEN TWO LAYERS OF REBAR WITH A MESH INTERVAL OF 100 mm AND REBAR DIAMETER OF 20 mm.

Attenuation, dB (ratio) for frequency	100 MHz	500 MHz	1 GHz
Distance between two layers of rebar, mm 30 100 200	 20 (10) 25 (178) 25 (178)	 27 (22.4) 40 (100) 40 (100)	 45 (178) 58 (251) 65 (1780)
Ratio of attenuation change for spot frequencies for different distances between two layers of rebar 30 to 200 mm	17.8	4.5	10
Average ratio of attenuation change for different distances between two layers of rebar 30 to 200 mm	10.8		

The findings represented in Tables 1 – 6 can be used to analyse and evaluate the influence of one or the other concrete's parameter on the shielding efficiency, and selection of the most suitable (for specific conditions) means to improve shielding efficiency. Comparison of findings presented by various authors returned a fair match (difference does not exceed 15%). At the same time, it is necessary to understand that the findings are connected with a specific material in a specific environment. Real materials and real conditions of use of these materials can differ significantly from those used in the experiment, which results in a significant change of shielding efficiency. Moreover, these changes can occur and gradually alter with time for the same material due to natural reduction of water content in the new concrete, which can significantly impact the shielding efficiency (Table 2).

III. COMPOSITE CONSTRUCTION MATERIALS WITH IMPROVED ELECTRIC CONDUCTIVITY

Composite materials with improved electric conductivity (intended for electromagnetic shielding) were first developed and studied back in the 1970s (in other words, about 50 years ago) [6, 7]. Since that time many new composite construction materials have emerged, which are mostly based on concrete with different additives improving its electric conductivity and, consequently, its shielding capacity. These materials are developed in China, India, USA, Russia and many other countries, and the results of their testing are published in many scientific papers, such as [8 – 16] and others.

The following products are used as additives for concrete: conductive powder (mostly coal, graphite and metal), carbon filament, carbon nanotubes and short pieces of steel wire. The recipes of such composite construction materials have been patented in many countries (US patents: 2868659, 3207705, 5346547, 5422174, 6214454, 6503318, 6821336, 7578881, 8067084, 8617309, 8968461, 9278887 and others; patents of Russia: 2545585, 2345968, 2234175, 2405749, 2291130 and others; patents of China: 1282713, 1293012, 1298663, 1844025, 101030454, 1313410, 103979853, and others).

The portion of graphite-carbon mixture can reach 25-35%, and in some cases – as high as 75% of the total material weight. Clearly, this portion of graphite and carbon in a concrete mix determines: 1) a rather high price of the final product; and 2) reduces its mechanic strength.

In Russia, it has recently become fashionable to use shungite as a conductive filler for construction materials. Shungite is a natural mineral composite material, consisting of fine-grained crystal silicate particles in an amorphous carbon matrix, Fig. 2.

Fig 2: Natural shungite

Shungite is excavated in Zagozhyn deposit (Republic of Karelia). Construction materials based on magnesium-shungite mixtures are produced in Russia by "Alfapol" company (patent of Russia No. 2233255). Shungite mineral of the third group is used as construction material. This group represents a natural composite material, which consists of 26-30% of carbon and 56-60% of silicate particles. Being a construction material, shungite mixtures are applied on surfaces of shielded premises as a finishing layer. In order to improve shielding efficiency, it is possible to use multi-layer shielding by combining a plaster compound with a metal mesh.

According to developers, the price of plaster-shungite mixtures is comparable to the price of usual construction materials.

Testing of radio-shielding properties of this material [17 - 19] in a broad range of frequencies was performed on a wall model made of plywood with a layer of shungite plaster "Alfapol ShT-1" applied onto it (15 mm thick), Table 7.

TABLE 7: SHIELDING EFFICIENCY OF SHUNGITE PLASTER "ALFAPOL ShT-1"

Frequency range, MHz	3 - 30	30 - 300	300 - 1200
Attenuation, dB	6 - 10	8 – 14	12 - 16

The dry mixture consists of natural shungite powder, active magnesium oxide in the form of caustic dead-burned magnesite (MgO) powder and a modifying additive. In order to prepare the plaster, a dry mixture is mixed with an aqueous solution of bishofite ($MgCl_2$).

The same type of plaster (RES-1) is produced by a Ukrainian company "Rudus" at 1.5 USD/kg of dry mixture together with a liquid polymer solution (Fig. 3).

Fig 3: Shungite plaster RES-1 produced by a Ukrainian company "Rudus".

Also manufactured is protective concrete based on shungite. However, there is no adhesion between shungite particles and cement stone, and thus it is very difficult to obtain a homogeneous mixture when mixing shungite powder with cement. Consequently, these particles can be viewed upon as conditional pores in the cement monolith. In connection with this, in order to prepare the concrete mixture, special magnesium cement (10%) is used, which features higher adhesion to shungite (85%). Magnesium cement is a type of construction binding material based on magnesium oxide. The latter is obtained from magnesite (a widely spread mineral – magnesium carbonate $MgCO_3$) by furnacing at high temperatures with further grinding.

Unfortunately, the cost of such concrete is not known and its shielding capacity is described in promotional materials in an inaccurate and indistinct way.

The University of Nebraska (USA) developed an improved recipe of conductive construction reinforced concrete (US Patents 8968461, 9278887), Table 8. This is promoted as material specially designed for HEMP protection.

TABLE 8: COMPOSITION OF CONDUCTIVE REONFORCED CONCRETE ACCORDING TO US PATENT 8968461 AND 9278887

Components	Percent
Type I cement	20.9%
Silica fume	1.1%
Sand and gravel taconite sand	20.1%
Taconite aggregate	23.5%
Carbon particles (0.7 mm max particle size)	2.0%
Carbon particles (2 mm max particle size)	5.6%
Carbon particles (10 mm max particle size)	8.0%

Graphite powder (0.15 mm max particle size)	1.2%
Water	10.1%
Steel fiber (1 in.)	3.3%
Steel fiber (1.5 in.)	2.7%
Steel fiber (fine) steel shavings	1.0%
Superplasticizer (High range water reducer)	0.4%

Taconite, which accounts for 23% of this concrete mixture, is a banded iron formation (one of the forms of iron ore). The recipe does not mention that the concrete is strengthened with several layers of steel mesh.

The component analysis of this construction material shows that its recipe does not contain any revolutionary or break through approach. However, the authors of these patents (primary author – Professor of Civil Engineering at Nebraska-Lincoln University, Dr. Christopher Y. Tuan) launched a powerful worldwide advertisement campaign, where they advertised unbeatable (in their opinion) features of their unique construction material (known as EMB3). They established a separate marketing company which promoted this material in the market and obtained corresponding investments into the project.

Fig 4: Erection of protected building using EMB3.

The main advantage of this material (according to the author) is lower material cost (by 60%) compared to similar materials and higher concrete strength (by 28%). According to the author, he managed to reduce the cost of the material to 300 USD per cubic yard (about 0.8 cubic meters), whereas the cost of common concrete is 120 USD per cubic yard.

When constructing a building using this composite material (Fig. 4), pouring of rebar is performed layer by layer as each layer contains specific filler.

The promotional material [20] suggests a unique feature for construction materials (Fig. 5). But this promotion does not show the specific (per 1 cm of thickness) attenuation (attenuation rate) introduced by material. In other words, it is unclear what the thickness and water content of material is (for which the chart is built). Indeed, the water content of concrete will significantly change during drying out, and simultaneously its resistance will change resulting in changes of the shielding capacity, Table 9 [21].

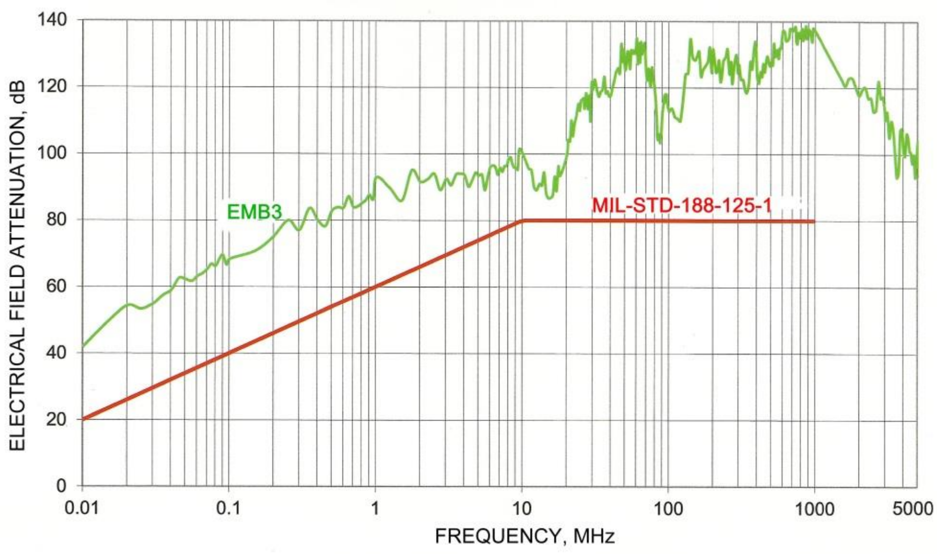

Fig 5: The feature of conductive EMB3 concrete (upper chart) being advertised and the requirements to shielding to ensure HEMP protection according to MIL-STD-188-125-1 standard.

Personal communication with the manager of Omni-Threat Structures, who represent this material in the market, revealed that the attenuation rate introduced by the material is about 10 dB/in (~4 dB/cm), which is actually not so prominent. The representatives of the company do not possess the data on how conductivity and shielding efficiency change as a function of water content in the material.

TABLE 9: CHANGES IN CONCRETE RESISTANCE WITH TIME [21]

Measured resistivity (Ohm• m) over time for material:	Day 10	2 Mouths	2 Years	Change ratio for 2 years
Conventional concrete mix	38	265	720	19
Conductive mix 1	2.3	6.0	95	41
Conductive mix 2	2.0	5.2	38	19

It should be noted that if a feature represented in Fig. 5 is true, it means that the efficiency of electromagnetic emission shielding by new concrete is close to the shielding efficiency of HEMP-protected premises covered with copper sheeting, which is commonly used for internal lining (Fig. 6).

Fig 6: HEMP-protected premises lined with copper sheeting.

The copper's high conductivity stipulates its capability to reflect the falling electromagnetic wave, especially in the range of relatively low frequencies (100 kHz - 100 MHz), which are specific for HEMP (Fig. 7).

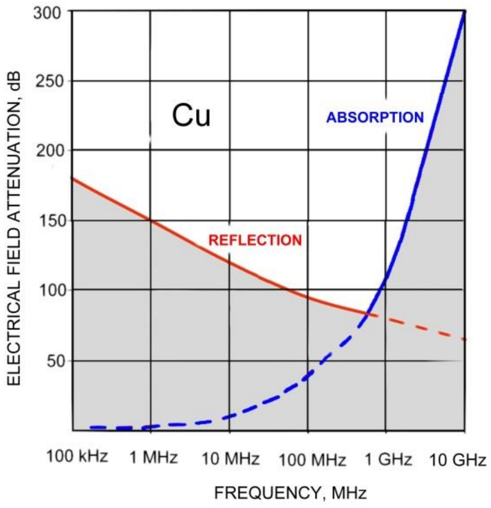

Fig 7: Efficiency of electromagnetic fields shielding by copper sheeting, which is used for lining of protected premises

The conductive concrete mentioned above also features high electric conductivity and thus, based on the feature mentioned in the advertisement material (Fig.5), its shielding capacity is determined by its ability to reflect the electromagnetic wave.

Usually, in order to check the premises' shielding efficiency, a receiver of emissions with a directional antenna is located interiorly, while a transmitter with the second directional antenna is located outside facing the first antenna. The difference between the emitted and received signals determines the level of its weakening, stipulated by the wall's shielding effect (Fig. 8).

Fig 8: Measuring the premises shielding efficiency

The copper lined walls provide excellent results of measurements. A good result was also obtained when using the same method of measuring for a new American concrete.

But here at least two questions arise:

The first: common electronic equipment of power industry facilities can resist the electromagnetic field's density of 10 V/m in accordance with the request of general standards on electromagnetic compatibility. This means that in order to reach the level acceptable for electronic equipment, the field density should be reduced from 50 kV/m to 10 V/m (which is in 5,000 times). But 100 dB (and even more) provided by this construction material over a broad frequency range means 100,000 times reduction! Do we really need this protection in practice, considering that the construction material being offered costs 3 times more than a common construction material (and since the erection technology is more complicated, perhaps, it costs even more)?

The second question is related to the material's properties. To be precise, with its ability to weaken electromagnetic emission through reflecting of the wave falling onto it. The problem is that this common method of HEMP protection is not acceptable to the electric power industry, since the sources of electromagnetic emission, including HEMP, are located not only exteriorly, but also in the interior of these facilities. The internal sources of emission are represented by cables running from outside into the protected rooms. The number of these cables is too large to run each core through a special HEMP filter. The electromagnetic wave, emitted by a cable inside the shielded room, reflects from a lined surface of a wall (ceiling, floor) and falls on sensitive electronic equipment located in the protected premises. Moreover, since the reflection angles can be unpredictable, this can result in emission strengthening and concentration of electromagnetic energy in the area of sensitive electronic equipment.

Unfortunately, all the common shielding sheet conductive materials: films, fabrics, paints, varnishes, etc., can reflect the electromagnetic wave falling onto them (this is actually the property that stipulates their protecting ability). Therefore, they can be efficient in protecting a small group of electronic devices, located in an enclosed area with cables protected from over-emission interiorly, e.g. cabinets with electronic equipment and filters, mounted on cables coming from outside. These cabinets, having a capacity to reflect an electromagnetic wave falling onto them, can ensure highly efficient protection of electronic equipment, provided interiorly there is no source of emission.

What is the solution for large premises containing many different types of highly-sensitive equipment and with many cables coming from outside? It seems that there is also a solution for this situation.

IV. MATERIALS ABSORBING ELECTROMAGNETIC EMISSION

There are a lot of recipes of construction materials with radio-absorbing properties in [22 - 24]. Common drawbacks of all these materials are their low efficiency at low frequencies (hundreds of kilohertz to hundreds of megahertz), complexity of making mixtures and its high cost. The recipes, based on ferrite powder developed in Japan, which ensure high absorbing at low frequencies, are way too expensive for broad use.

It is known from the theory of electromagnetic waves spreading, that porous materials contain a low index of EMP reflection due to close values of impedance of the material's surface and the air surrounding it. Thus, porous construction materials are rather suitable as radio-absorbing materials.

The Patent of Russia No. 2234175 describes radio-absorbing porous concrete, which consists of highly-porous glass or ceramic pellets, coated with ferrite and (or) conductive material, and ferrite and (or) conductive powder with an adhesive agent. The patent No. 102627436 suggests mixing of cement with porous pumice particles and adding technical carbon (1-2%).

The recipe of one of the best porous concretes is described in Patent of Russia No. 2545585, which suggests toproduce radio-protection construction concrete based on cement, sand and porous pelleted filler. The radio-absorbing properties of concrete are stipulated by adding carbon-containing filler, which constitutes a structured gel (up to 40% of the cement's volume), consisting of 5-10% of aqueous solution of polyvinyl alcohol (51-63%), sodium lignosulfonate (4-7%), 25% ammonia solution (9-12%) and electrotechnical carbon (24-30%).

The specific (per 1 cm of concrete thickness) absorption described in the patent shows fair properties of this material (Fig. 9), provided it is sufficiently thick.

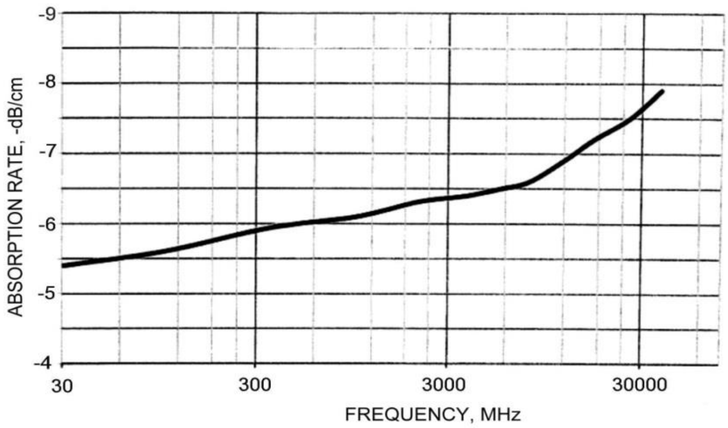

Fig 9: Specific absorption of concrete according to Patent of Russia No. 2545585.

The Patent of Russia No. 1840794 suggests strengthening the radio-absorbing properties of concrete by modifying the clay pellets – a common construction material, which is widely used as a concrete filler. In order to do this, the clay pellets are coated (by pouring) with two layers of special suspension with further drying at 80-90 degrees. Composition of suspension: water (81.5%), sulfanol (1.9%), soot (11.9%), liquid glass (4.7%). This composition of suspension ensures 50% soot content in the final coating. According to the developer, the radio-absorbing clay pellets provide repeated re-reflection of a falling electromagnetic wave, thus resulting in its full absorption. The reflection index of such radio-absorbing material does not exceed 10%, the absorbing capacity of material exceeds 0.6 Wt/cm^2 (unfortunately, without any reference to the frequency range).

Concrete is not the only material featuring radio-absorption. There are other construction materials, which feature the same properties.

Fig 10: Radio-absorbing construction material based on foamed ceramics Ceramopen^{TM}.

One of these materials is called Ceramopen^{TM} (Fig. 10) developed by the Russian company "Cerapen". This material is based on glass-ceramic foamed ceramics features attenuation of more than 30 dB, whilst the reflection from a flat surface (-13 dB), is not more than 5%. Additionally, Ceramopen features low water absorption (less than 1%) and good heat insulating properties.

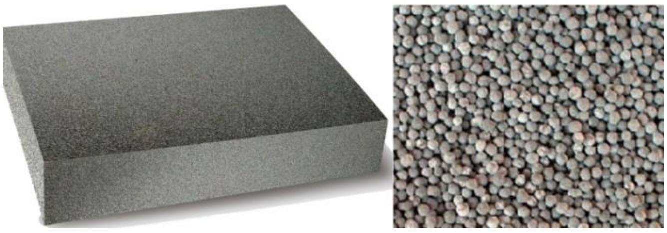

Fig.11. Foam glass in the form of construction blocks and pellets

Another form of foamed construction material with radio-absorbing properties is foam glass. The radio-absorbing properties of the foam glass are provided by the porous structure of the material and availability of a carbon-containing component, which is used as a gas-forming agent during foam glass production (Patents of Russia No. 2255058, 2255059, etc.). Compared to conventional absorbers, the foam glass materials feature such important benefits as mechanical strength and low weight (Fig. 11).

The world leader of foam glass production is Pittsburgh Corning Company (USA). It produces the foam glass product under the "Foamglass" trade mark. Other large foam glass producers are Chinese Gansu Pengfei Insulation Materials Co. Ltd., Gomel Glass Factory in Belarus, ICM Glass in Russia and others.

The recipes, properties, production technologies and research findings for foam glass are described elsewhere [25 – 27] and others.

The price of foam glass panels with dimensions 600 x 450 x 50 mm produced by Pittsburgh Corning is about 30 USD per square meter.

In order to ensure additional strengthening of radio-absorbing properties of foam glass, zinc oxide, graphite and some other chemical elements [25] need to be added. Foam glass is produced by baking this mixture at 750ºC for 30 minutes with further cooling. The obtained material demonstrated minimum reflection index -15.6 dB at 12.0 and 12.4 GHz frequency. It is recommended to control the absorbing capacity of the obtained material by changing zinc oxide inclusion.

The foam glass pellets, (Fig. 10) coated with carbon-containing material, in addition to carbon contained in the pellets, is used for pouring between the walls made of thin insulation material (up to single-face laminate). The obtained finishing panels will be attached to the walls of the protected premises. According to Engineering and Marketing Center of "Vega" Corporation, who represent this technology, a panel like this provides specific attenuation of electromagnetic field of at least 6 dB per centimeter of the filling layer (at 4 GHz frequency). This allows 1,000 times reduction of electromagnetic field at 5 cm thickness [28].

Pelleted foam glass without additional carbon coating costs about USD 140 per cubic meter. Unfortunately, "Vega" Corporation did not answer my question regarding the price of panels with pelleted foam glass filling and special coating.

Ferrite is the most efficient radio-absorbing material for the frequency range corresponding to HEMP. Ferrite is a magnetic material, which is a chemical compound of metal oxides (nickel ferrite ($NiFe_2O_4$), zinc ferrite ($ZnFe_2O_4$) and others), which are artificially produced as magnetic materials. Polycrystalline ferrites are produced according to ceramic technology. The properly shaped elements are made of ferrite powder, obtained from a mixture of initial ferrite-producing components and adhesive agent. Then these elements need to be baked at 900-1,500ºC in the air or in a special gas environment.

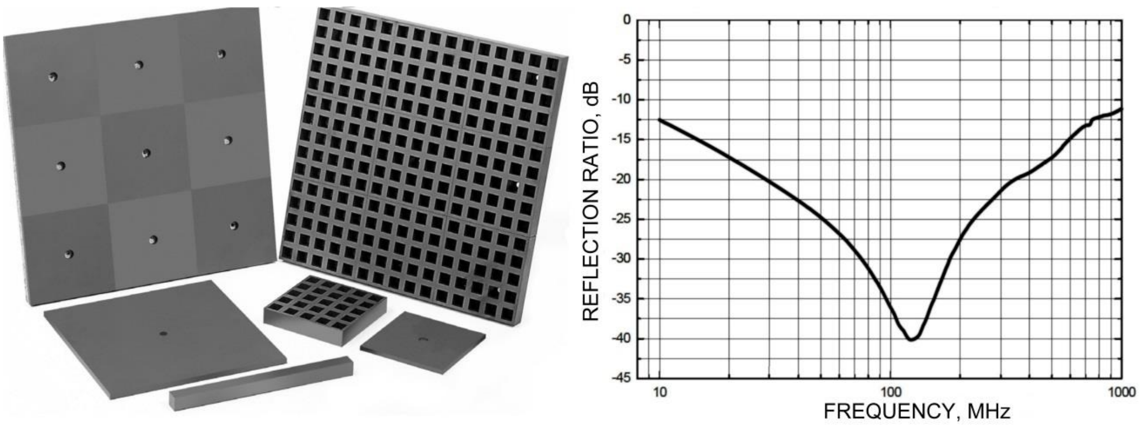

Fig 12: Ferrite lining panels and their standard specification.

The ferrite radio-absorbing material is produced in the form of finishing tiles, which will be attached to the interior walls of the premises. The standard tile size is 100 x 100 mm. Some manufacturers use these tiles to make 300 x 300 mm and even 600 x 600 mm lining panels. These panels feature good absorbing properties in the required frequency range (Fig. 12).

These panels are produced by many companies, such as ETS-Lindgren, Samwha Electronics, Holland Shielding Systems BV, Fire-Rite Products Corp., Riken Environmental System Co., Global EMC UK Ltd, Cuming Microwave Corp., Amidon Associates, Inc., Pioneer EMC Ltd., Siepel and others.

Unfortunately the cost of such panels is rather high. For example, a 300 x 300 x 5.5 mm panel costs more than USD 50, whereas 600 x 600 x 6.7 mm will cost as high as USD 220. One 100 x 100 mm tile costs from 6 to 9 USD, depending on the manufacturer. This cost may prevent a broad use of this material for premises lining at power plants and substations. However, this material can be used as a radio-absorbing partition inside the cabinets with especially sensitive and critical electronic equipment.

V. ANOTHER METHOD OF REDUCTION OF HEMP ELECTROMAGNETIC FIELD STRENGTH IN THE POWER INDUSRY PREMISES CONTAING ELECTRONIC EQUIPMENT

As mentioned above, electromagnetic emission of HEMP, which can penetrate through walls into the premises of power industry facilities with electronic equipment, is not the only source of emission affecting the electronic equipment. Another very powerful source is represented by a pulse electromagnetic field, re-radiated by hundreds of cables running into the premises with electronic equipment from outside. These cables act as antennas, absorbing HEMP energy from a large area and delivering it to the premises containing electronic equipment. It is impossible to mount an expensive HEMP filter at each core of each multi-core cable, when there are hundreds of them. However, it is possible to reduce the level of cable-emitted pulse without these filters. To do this, the cables need to be closed with electromagnetic screens right at the place of their entrance into the protected premises. It is recommended to use solid (non-perforated) cable trays as the screens (Fig. 13).

Fig 13: Non-perforated metal cable trays preventing re-emission from cables entering the protected premises from outside

Fig 14: Construction elements for enclosed solid cable trays

Both solid cable trays with lids and their construction elements are available in the market (Fig. 14). The latter are made of aluminum, galvanized steel, steel with single-layer spraying of protecting insulation layer and galvanized steel with additional powder spraying.

Steel trays feature the best protecting properties at HEMP frequencies. The cost of galvanized steel (steel thickness - 1.2 mm) trays ranges from USD 2 to USD 15 per meter of length (depending on the width and height). Steel trays with powder spraying of insulation coating are a bit more expensive. For example, a tray 50 x 50 x 1.2 mm would cost about USD 4 per linear meter, whereas a tray 200 x 50 x 1.2 mm – more than USD 7 per meter.

Plastic trays with metal coating are cheaper, but they are not suitable for this purpose. Due to very thin metal coating they work exclusively at very high frequencies, which fall outside the HEMP frequency range.

Reflection of an electromagnetic pulse, emitted by power cables located in the metal tray into the inner area of the tray, can result in an unfavorable effect of this emission onto adjacent control cables, located in the same tray and connected to electronic equipment. That is why power and control cables must be run in separate trays, while control cables must be split into groups and placed in separate sections of sectioned cable trays (Fig. 15).

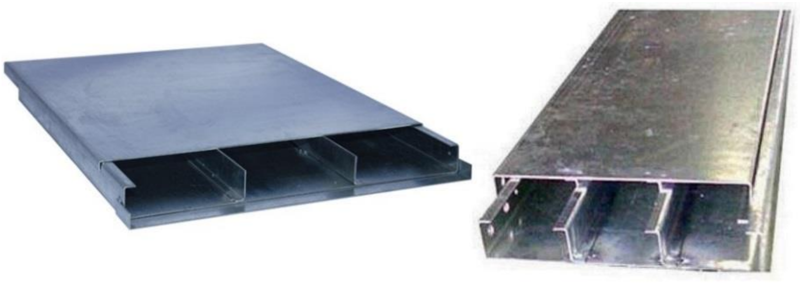

Fig 15: Sectioned cable trays

If hard cable trays are inconvenient to use, flexible metal tubing can be used, especially for control cables with a small section (Fig. 16).

Fig 16: Flexible electromagnetic screens made of flexible metal tubing

VI. REDUCTION OF HEMP IMPACT ON ELECTRONIC EQUIPMENT DUE TO ARCHITECTURAL SOLUTIONS

According to [29], modern buildings built from common construction concrete and metalized glass (widely used for UV and IR reflection) weaken electromagnetic emission by 13-14 dB more than the old buildings. This weakening can reach 20-25 dB in the frequency range from 800 MHz to 18 GHz.

Unfortunately, this frequency range is far away from the HEMP range. However, in an earlier publication [30], it was discussed that not very modern concrete buildings of a frequency range 1 to 100 MHz, the electromagnetic field attenuation was specified as 20 - 25 dB, and for a frequency of 100 kHz as 10 - 15 dB.

The further reduction of penetrating electromagnetic emission can be obtained by placing the critical electronic equipment into the internal building premises having no exterior walls and windows (Fig. 17).

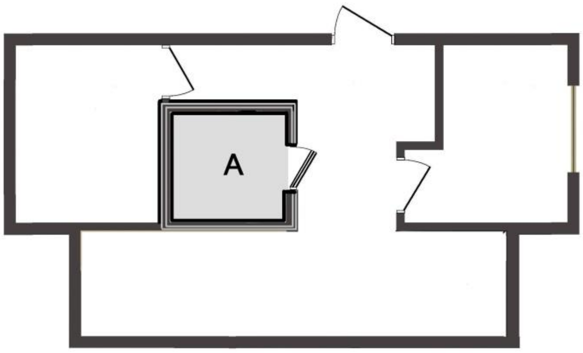

Fig 17: An example of floor layout with internal protected premises "A".

Moreover, this protected room should not have any windows and should be equipped with metal doors with conductive rubber sealers along the perimeter. The inner surface of the walls in this room can be lined with some shallow thickness (3 - 4 cm) panels coated with radio-absorbing powder. Another option: the walls of these inner insulated premises should be made of radio-absorbing foam glass blocks.

VII. CONCLUSION

None of the above mentioned approaches to external protection of rooms full of electronic equipment from HEMP is ideal from both efficiency and cost effectiveness standpoints. Therefore, the most sensible in our opinion is to ensure comprehensive protection based on joint use of non-expensive construction materials with the required properties, each of which provides at least partial protection. For example: concrete reinforced with metal rebar (as material that partially reflects an electromagnetic wave falling on its external surface); panels coated with inexpensive radio-absorbing powder (as inner lining); sectioned non-perforated metal cable trays (as shields protecting the internal area of the premises from re-emission from cables entering from outside); placement of highly sensitive and critical electronic equipment in the internal premises of the building that have no windows but have metal doors, and mounting of this equipment in special metal cabinets with radio-absorbing ferrite partitions interiorly.

In any case, the consumer shall balance all the “pros” and “cons” of each option of external protection considering his/her financial position. This article should assist the consumer in making the optimum solution.

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