Immunity of camera systems against electromagnetic interference

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Doctoral Thesis Summary

Tomas Bata University in Zlín

Tomas Bata University in Zlín
Faculty of Applied Informatics

Dissertation Thesis Statement

Immunity of camera systems against electromagnetic interference

Odolnost kamerových systémů vůči elektromagnetickému rušení

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ABSTRACT

The primary goal of the doctoral thesis is to increase the immunity of security cameras against electromagnetic interference. Security cameras constitute one of the fundamental techniques of physical guarding on how to detect and eliminate crime. Unfortunately, increasing the use of electronic and electric devices causes an increase in electromagnetic interference, which may affect the correct function of the devices. This is particularly the problem for security devices where great emphasis is placed on reliability.

The work aims at the design and implementation of shielding enclosure for security cameras. The draft is verified by CST Microwave Studio electromagnetic simulation software, which allows determining expected shielding effectiveness and distribution of electromagnetic radiation. The final product is validated by testing them in both a GTEM cell and in a semi-anechoic chamber.

ABSTRAKT

Hlavním cílem dizertační práce je zvýšit odolnost bezpečnostních kamer vůči elektromagnetickému rušení. Bezpečnostní kamery představují jednu ze základních technik fyzické ochrany, jak odhalovat a odstraňovat zločiny. Nicméně rostoucí používání elektronických a elektrických zařízení způsobilo zvýšení elektromagnetického rušení, které může ovlivnit správnou funkci zařízení. To může být problém obzvlášť pro bezpečnostní zařízení, kde se klade velký důraz na spolehlivost.

Práce se zaměřuje na návrh a realizaci stínícího krytu pro bezpečnostní kamery. Návrh je založen na teoretických podkladech a ověřen pomocí elektromagnetického simulačního softwaru CST Microwave Studio, který umožňuje určit předpokládanou účinnost stínění a rozložení elektromagnetického záření. Práce obsahuje modely GTEM komory a koaxiálního vedení, jejichž reálné modely byly využity pro praktické testování návrhů. Cílem také bylo odhalit vliv nepatrného narušení krytu na stínící účinnost.

CONTENT

1. INTRODUCTION

Currently, electromagnetic compatibility has become to be a severe problem for electronic and electrical devices design and implementation, especially for security devices, where the critical factor is reliability. There are many aspects why eliminate electromagnetic radiation, namely due to electromagnetic field effects on the human body [1], [2], or device signal eavesdropping [3], [4]. That is the reason why the demand for protection against undesirable effects of electromagnetic interference has increased.

Electromagnetic compatibility can be defined as an ability of electronic and electrical product work as intended in an electromagnetic environment. In other words, it is the ability of a product not to generate electromagnetic disturbance, which may affect other devices in the vicinity. According to [5], a device can be perfectly reliable, but it is not usable if it cannot work in the electromagnetic environment. In the case of security cameras, interference can appear as "a loss or disruptions, interruption of communication between components, reset of storage devices or other disruption of device functions that can make its normal usage impossible." [6]

Electromagnetic compatibility includes two other terms, namely electromagnetic interference and susceptibility or immunity. Electromagnetic interference is a signal generation process which is transferred via electromagnetic coupling into a receiver. In essence, disturbance supervene when the receiver works in an undesired manner after the signal reception. [7] Interference aimed at identifying disturbance sources and parasitic transmission paths as well as signals measurement and description. It means electromagnetic interference deals with disturbance sources and their elimination.

Electromagnetic susceptibility defines the immunity or tolerance of components and circuitry to all sources of interfering electromagnetic energy. In other words, electromagnetic immunity describes an ability of device works as intended without failures or with precisely defined permissible limits. [5] In comparison with interference, susceptibility deals with techniques for protecting the device against harmful signals. It means consequence elimination. [5] The way to protect the device is to pay attention to printed circuit board design or shielding material application.

How was mentioned, electromagnetic interference continues to be a significant problem for electronic and electrical devices, especially for security cameras where the great emphasis is placed on reliability. Therefore, there was born an idea to find a solution on how to protect the camera. The thesis focuses on finding the solution for the issue of device protection against harmful electromagnetic energy. The way how to make it is in shielding. The thesis describes the shielding enclosure design verified by simulation software and practical measurements.

2. CURRENT STATE OF SOLVED TOPIC

Currently, the electromagnetic immunity issue of security devices represents a relatively unknown area. Nowadays, there are not many security cameras that can reliably resist electromagnetic interference higher than 30 V/m. The reason is simple because current European standards require meeting device resistance against disturbance level only around 10 V/m for the residential environment. [8] Standards used to electromagnetic susceptibility tests describing the Theoretical background section. There are many research publications, technical instructions, and national standards to protect electronic devices in the general sense. However, there are only several publications [9], [10] related to the electromagnetic protection of security devices, especially cameras. Unfortunately, these theses offer just a limited proposal for a solution based on incomplete information. Other publications focus on interest to increase electronic devices electromagnetic immunity in general [11], [12], [13] or shielding effectiveness tests of existing solutions and offer improvements [14], [15], [16], [17].

For electromagnetic compatibility test, there is necessary to determine the electromagnetic environment where the equipment under test (EUT) works. The environment can differ in classes according to the used European standard, for example, CSN EN 61000-2-4 [18], CSN EN 55011 [19], or CSN EN 61000-4-3 [20]. European standards relating to electromagnetic compatibility describes a chapter called Theoretical Background.

European standards are detailed and provide uniform test procedures; however, there are also military standards [21], [22], [23] which apply to all devices or environments and give general test procedures. [23] The military standard [21] states an exciting point claiming that the facility may not be sensitive to a radiated electric field at specific frequencies; nevertheless, it can be susceptible to electromagnetic with the lower limit levels environment at the same frequencies. Another standard [22] describes cameras as a potential inadvertent source of electromagnetic interfering energy; therefore, cameras should be shielded. The electromagnetic environment is not static, so limit levels should be adapted according to current conditions. The standard [22] also claims that levels should cover most situations, including "back door" effects, namely radio-frequency high-power threat.

The fundamental factor in shielding enclosure production is the types of material used. Currently, there are several materials [24], [14], [25] suitable for this purpose; unfortunately, not all achieve the required results. Therefore, scientists have started to develop favorite intrinsically conducting polymers (ICP) [11], [25]. Publication [26] describes ICPs as organic polymers with electrical, magnetic, and optic properties similar to traditional metal materials. Publication [11] completes the explanation by stating that the ICPs advantage is proper properties combination such as pleasant conductivity, low density, and corrosion resistance. Parameters changing as oxidation state, morphology, or chemical structure can affect final electrical conductivity value. [25] Concerning shielding efficiency, it depends on which ICP variant is selected because there are many types such as polyaniline, polypyrrole, polythiophene, polyphenylene vinylene. [11], [25] Publications [11], [12], and [26] state that ICPs may consist of metal, graphene, graphite, carbon, or another conducted substance. These substances should improve electrical, magnetic, and dielectric properties and ensure non-transparency to electromagnetic radiation. [12], [11] Except for the materials mentioned above, there are also protections in the form of ultrathin substance, which may be applied on the enclosure surface. One of these solutions published the researchers from Drexel University and the Korea Institute of Science and Technology [27] who developed nano-film based on MXene [28], allowing suppressing electromagnetic radiation.

The publication [9] includes a sophisticated suggestion of shielding enclosure; nevertheless, there is not enough information about shielding enclosure, and the author states in conclusion, that the thesis is not complete. The author measured MIP-6430-2 security camera electromagnetic interference located inside of box according to adjusted EN 55022 European standard in the frequency range from 30 MHz to 2 GHz. Publication [29] defines the term shielding enclosure as a structural means to protect inner against electromagnetic interference extern sources. It means the box should able to eliminate electromagnetic radiation passing in both directions. In other words, the shielding enclosure should suppress incoming and outcoming interference. If it takes into consideration, it is possible to agree with the author's [9] claim that the design shielding enclosure eliminates the electromagnetic radiation level.

Although the thesis does not provide enough information to compare camera interference with or without a shielding box, the author offered an elegant solution. Construction of the structure is created by stainless steel, which is a corrosion-resistant material. It is essential to pay attention to a corrosion-resistant material search because corrosion can significantly affect electromagnetic immunity. The cover thickness is minimal, only 1 mm. It ensures the low weight of the final product. The exciting solution is lens protection because the author chose "microwave ovens" technology, also known as a Faraday cage which is an easy way to interference suppression. Another answer is lead glass or other similar materials use; however, there can be a problem with realization and the desired attenuation achievement in the given frequency spectrum. The author used a conductive strip to bind the box with shielding foil. Metal contact strips from Laird Technologies Company ensure the seal between the enclosure and opening cover. [9]

Another interesting publication [10] regarding security camera electromagnetic immunity deals with shielding elements rather than a cover design. The thesis combines all shielding technologies available on the market and provides advice on how to use them for this device. The publication uses a trial and error system and pays attention to both radiated and conducted disturbance. Nevertheless, the solution does not solve lens protection, but only plastic parts are covering by metallic material as the foil. The author [10] mentioned several notes about shields for devices, a better and cost-effective solution if electromagnetic interference generated by the printed circuit board cannot be eliminated during the design. [10] Author used ferrite beads to protect cabling against disturbance, which is the easy way to defend any commonly used unshielded cable. It was a great idea because there are many security cameras using cables sensitive to electromagnetic radiation. The thesis includes the results of two shielding material, namely Pure Copper Polyester Taffeta and ShieldIt Super, which are applied in layers on the Panasonic-WV-CP470 camera surface. It is necessary to mention that this improvement is not focused on security cameras but for cameras working in high electromagnetic interference level area, such as the GTEM chamber. [10]

Other publications [16], [30] focus on the general shielding enclosure, not on camera protection. The paper [16] aimed at the shielding effectiveness prediction based on the absorption cross-section technique [16], [31], which is realized using the reverberation chamber and is defined as a ratio of average absorbed power to average power density.

The detailed description of the current state is in the full version of this thesis.

3. OBJECTIVES OF DISSERTATION

The basis for the doctoral thesis is the author's experiences and consultations with experts in the field of electromagnetic compatibility; therefore, it was decided that the work will be focused on:

- proposing a shielding enclosure for security cameras based on electromagnetic simulations results,
- shielding enclosure practical implementation and testing its electromagnetic immunity.

Security cameras represent one of the most sensitive devices against electromagnetic radiation; therefore, the author decided to improve the current state by creating a shielding enclosure. Currently, security cameras should be able to reliable resist electromagnetic radiation about 10 V/m for the residential environment specified by European standards. In the industrial environment, the level of radiation is higher, approximately 30 V/m. However, immunity depends not only on the environment but also on the type of cameras and transmission medium. The application of the shielding enclosure ensures long-term device protection because there are cases when the security camera was not able to resist permanent electromagnetic radiation for a longer period. It is expected that a shielding box to protect security cameras in buildings will be used, particularly those with an increased danger of the jammer's use.

4. THEORETICAL BACKGROUND

This chapter's description is reduced only to essential theoretical topics related to other parts of this work. A detailed description of the academic background is given in the full version of this work. The following lines are mainly devoted to shielding and the GTEM chamber, which was used in the practical part.

4.1 Shielding Effectiveness

Publication [32] defines SE stands for shielding effectiveness as a ratio of a signal received from a transmitter without the shield to a signal gained from a radiation source with the shield protection. Shielding effectiveness essentially explains a material inserted loss and decide how shielding material eliminates the electromagnetic interference effect from a source. Publication [32] defines a shielding enclosure as a mechanical means to protect inner space from the external electric or magnetic field, and simultaneously it secures electromagnetic environment around construction against an internal electric or magnetic field effect. Shielding enclosure should consist of a metallic material with continuous electrical contact between adjacent parts of the structure.

According to publication [7], the following equation describes the shielding effectiveness based on the specific physical mechanisms of the shielding effect.

$$SE = R_{dB} + A_{dB} + M_{dB}\ [dB] \qquad (1)$$

Individual characters indicate:

R_{dB} - reflection losses caused by reflections between the interfaces;

A_{dB} - absorption losses caused by passing waves through the material;

M_{dB} - losses by multiple reflections passing through the material.

4.2 Gigahertz Transverse Electromagnetic Cell

The TEM test chamber offers a practically perfect EMS solution, enabling the generation of a homogeneous transverse field without unwanted emissions into the environment. TEM chambers are specially designed electromagnetically shielded spaces developed for EMC purposes, both for testing electromagnetic immunity and for measurement of disruptive emissions. [5], [6]

The chamber is formed by a closed space in the shape of a long pyramidal widening section of coaxial lines with an inner stripline conductor. The characteristic impedance along the entire length is constant and equal to 50 ohms. A broadband impedance matching of the GTEM chamber at high frequencies provides absorbent material while an internal resistor network ensures anechoic properties at lower frequencies at the end of the inner stripline conductor. The progressive electromagnetic wave propagates with a slightly spherical wavefront. [5], [6]

5. PROCESSING METHODS

The section describes the methods used for doctoral thesis completion. In addition to primary methods like analysis, synthesis, and experimental methods, the author uses a more advanced approach, namely numerical modeling or multi-criteria evaluation. All processing methods are listed in the following lines.

1) Analysis method - this method is used in the process of design. Electromagnetic immunity testing is a complicated process; therefore, it is necessary to decompose solved problems into smaller units, i.e., conducted and radiated susceptibility.
2) Synthesis method - this method is suitable for the progress of camera design. Knowledge gained during individual processes of electromagnetic immunity tests and electromagnetic interference measurement serves as a support to design the final product.
3) Induction method - this method provides general rules based on specific cases. The application method is suitable for the process of shielding material selection; however, there is only weak induction due to a small number of material representatives.
4) Numerical modeling - the method provides electromagnetic compatibility information about distribution and levels before the camera proposal realization. The result of the method advice what kind of changes should be performed.
5) Multi-criteria evaluation method - this method finds the ideal solution that helps to increase the shielding enclosure electromagnetic immunity. The box design process is sophisticated; therefore, there can be more than one solution, and the method finds its application.
6) Experimental method - this method searches the right solution pursuant experiments. The trial and error approach helps verify or disprove the hypothesis and knowledge from electromagnetic immunity assays.

6. EXPERIMENT AND RESULTS

6.1 Experiment – Evolutionary Algorithms

The evolutionary algorithms are applied to the input parameters (Tab. 1) instead of fixed parameters. That leads to automatic settings changing in each cycle without user interaction, and the program can look for the results approaching the desired electric field strength, which allows calculating shielding effectiveness. This way saved the total calculation time and computational requirements. The input parameters include the number of hole edges, the pitch between holes, radius and thickness of aperture, the angle of rotation for all holes, and the second angle rotating only even raw holes relative to the first one. The base of the experiment is Wolfram Mathematica software for scientific, technical, and mathematical calculations that defined parameters and run the CST Studio. CST Microwave Studio uses a specific function called macro, allowing to create a model, set, and run the project via VBA programming language. In other words, Mathematica runs evolutionary algorithms, and CST Studio performs the simulation tasks.

Tab. 1. Values of Input Parameters for Variable Iteration of Evolutionary Algorithms.

Algorithm	**Pitch [mm]**	**Radius [mm]**	**Number of Edges [-]**	**Angle of Hole Rotation [°]**	**Angle of Rotation for Even Raw Holes [°]**	**Thickness [mm]**
Firefly	1.889	1.766	4	223.410	91.902	2.618
SHADE	5.746	1.552	4	225.987	96.303	2.864
HCLPSO	2.336	1.934	4	312.634	178.745	2.672

The experiment involves only three selected evolutionary algorithms, namely the Firefly Algorithm (FFA), Success-History based Adaptive Differential

Evolution (SHADE), and Heterogeneous Comprehensive Learning Particle Swarm Optimization (HCLPSO). The detailed description of the algorithms is in the full version of this thesis.

6.2 Results – Evolutionary Algorithms

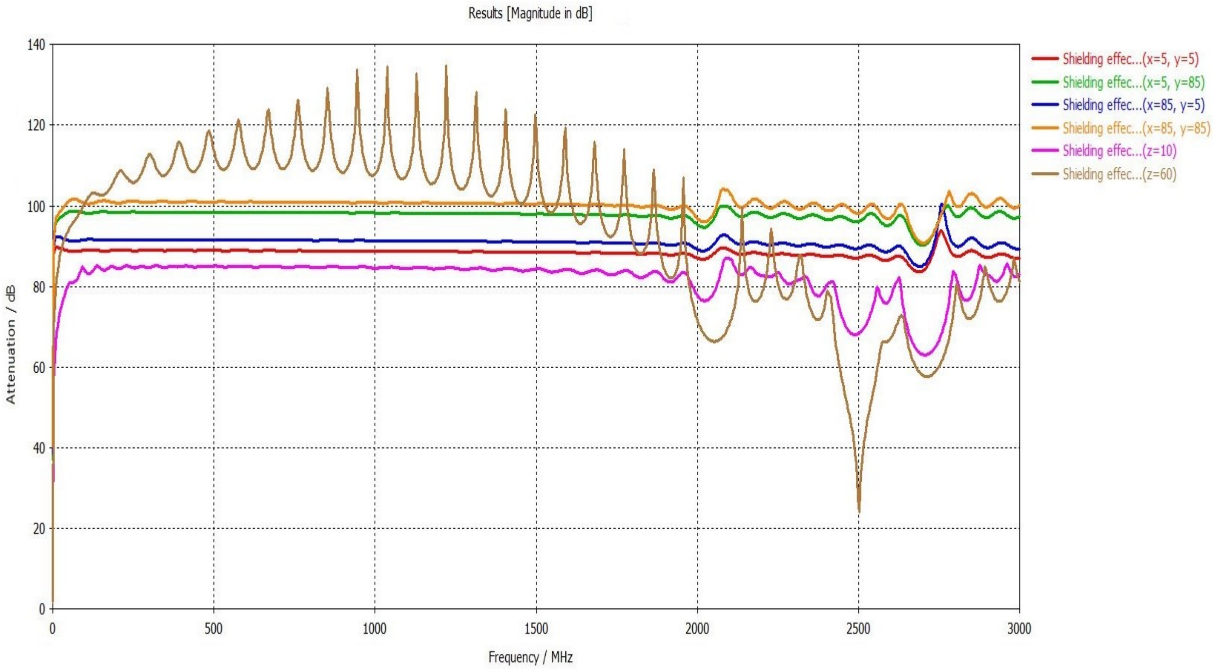

Fig. 1. Shielding Effectiveness of Box Designed by Firefly algorithm.

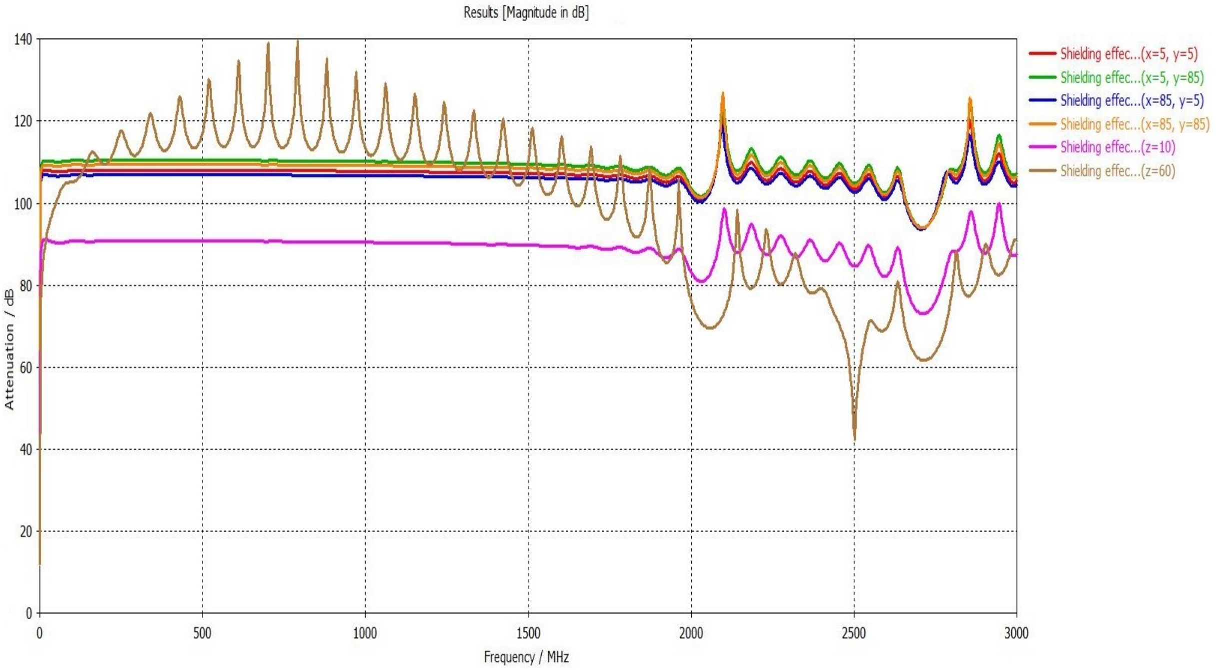

Fig. 2. Shielding Effectiveness of Box Designed by SHADE.

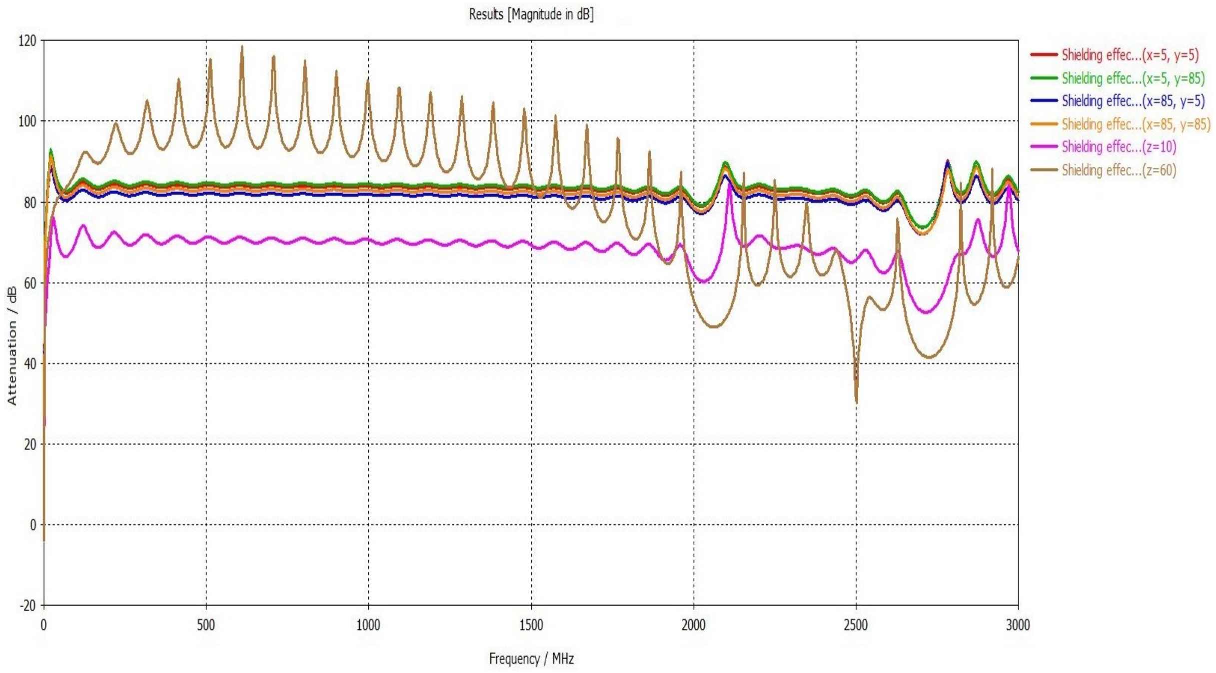

Fig. 3. Shielding Effectiveness of Box Designed by HCLPSO.

6.3 Experiment – GTEM Chamber

This section describes the experiment regarding the comparison of measurement techniques and simulation. The product designed by the evolutionary algorithms in the previous chapter was challenging to create due to the prototype's financial costs and sophisticated production technologies. Therefore, the author decides to design a simple alternative solution with the commercially available products which are more suitable for future work. The metal grid and perforated sheet metal were formed into a shielding cover suitable for wide-angle cameras.

The experiment consists of two-part; the first one includes simulation when the boxes were inserted into the GTEM chamber model, and their shielding effectiveness was calculated. The second part involves the practical measurement in the laboratory and the comparison with the simulation. The practical part of the experiment includes two cameras (KPC S230CWX and Vivotek FD8136B F3). The first step was a test of electromagnetic immunity of the cameras. In the analog camera, the quality of the video immediately dropped in the presence of an electric field, as the following figures show. IP camera was more resistant to electromagnetic fields, and the identification of interference was complicated. However, more detailed observations and tests have led to the assumption that visible image distortion is eliminated by the image compression that most cameras have. This assumption has not yet been verified, due to the complexity of the problem; therefore, it remains the subject of future research. The author would like to reiterate that so far, this is only a hypothesis. The author presented verified signs of IP camera problems in the presence of an electromagnetic field in the publication [80]. Testing took place in a semi-anechoic chamber and resulted in relatively high-intensity acoustic signals in specific frequency bands (489.2 - 800 MHz).

Fig. 4. Camera Streaming in the GTEM Chamber with a Level of 30 V/m.

Tab. 2. Parameters of Shielding Enclosure A.

Parameter	**Unit [mm]**
Box width	92
Box height	70
Box base width	112
Box base thickness	0.1
Diameter	0.2
Mesh size (side)	0.3
Diagonal of mesh	0.5

Tab. 3. Parameters of Shielding Enclosure B.

Parameter	**Unit [mm]**
Box width	92
Box height	70
Box base width	112
Box base thickness	0.1
Mesh diameter	0.2
Horizontal gap between meshes	6.5
Vertical gap between meshes	3
Shift between even and odd lines	3

Measuring equipment

- GTEM chamber – EMC-GTEM-250
- Probe - Frankonia EFS-10
- Signal generator - Rohde & Schwarz SMB 100A (100 kHz - 40 GHz)
- Relay Switching Unit - Frankonia FR-RSU
- Amplifiers - Frankonia RF-power amplifier (20 MHz - 1 GHz, 0.8 GHz - 2 GHz, 2 GHz - 6 GHz)

6.4 Results – GTEM Chamber

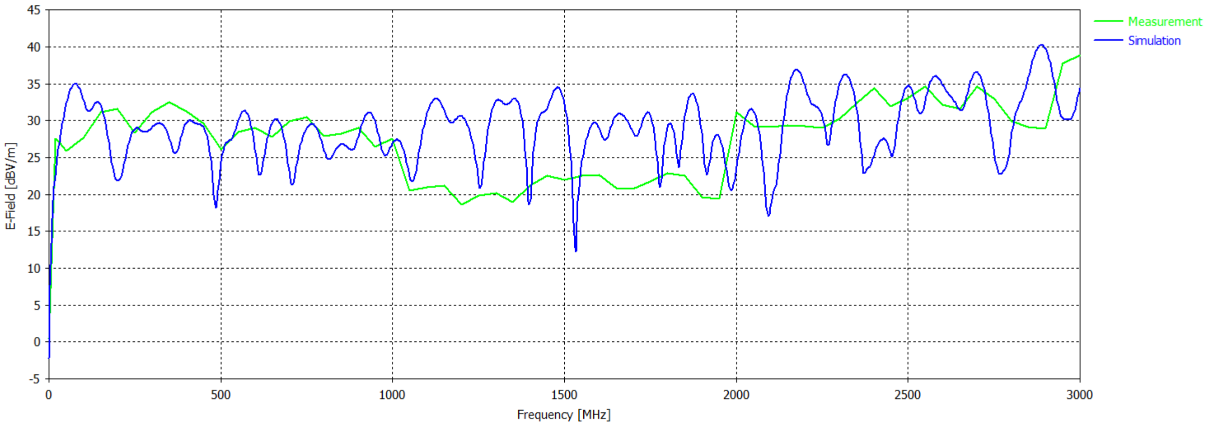

Fig. 5. Comparison of Simulation and Measurement.

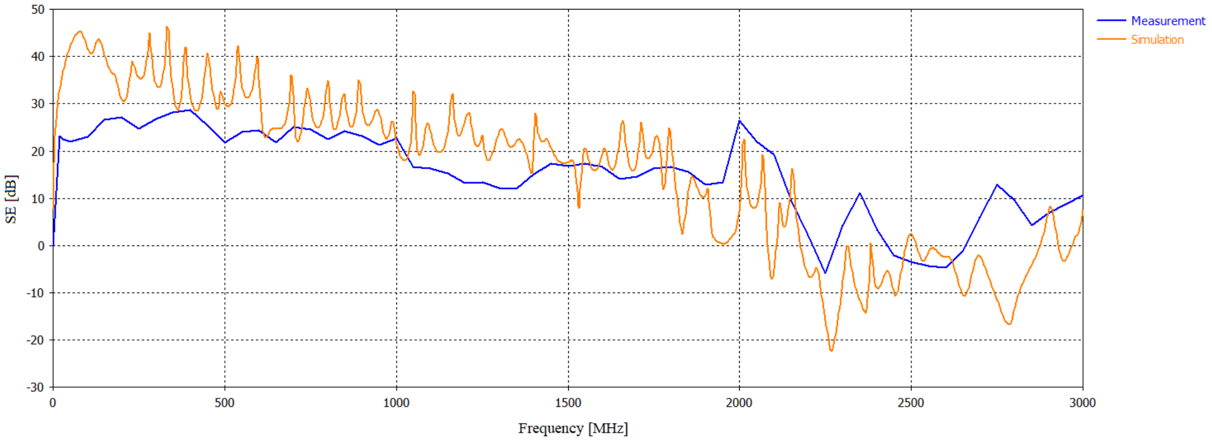

Fig. 6. Shielding Effectiveness Comparison of Measurement and Simulation – Shielding enclosure A.

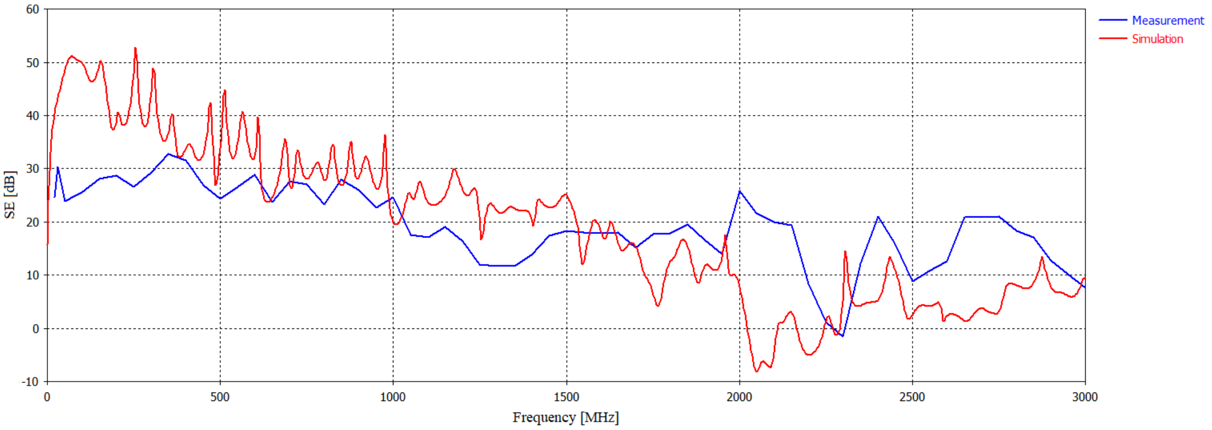

Fig. 7. Shielding Effectiveness Comparison of Measurement and Simulation – Shielding enclosure B.

The results of the electric field in Fig. 5 indicate the differences; it is because of the measurement devices and the technique which was used. The first trouble is the feedback probe, which provides data with a high degree of uncertainty. The second problem is the amplifier in the frequency range of 0.8 GHz to 2 GHz, which does not provide sufficient input signal amplification what can be seen in Fig. 5. The problem could also be imperfect of the GTEM chamber model, which had to be simplified due to computational complexity. The last limitation is the probe location, which can be a little bit different. The expected difference is approximately 1 cm. Fig. 6 illustrates the shielding effectiveness of box A. The results show that the box reaches satisfactory shielding properties at lower frequencies, especially up to 1 GHz, but poor values at higher frequencies. However, there is necessary to consider the limitation mentioned before. The benefit of this variant is almost perfect transparency, unfortunately, at the expense of shielding effectiveness. The shielding box B reaches similar values as the variant A although the transparency of the cover is considerably worse. The differences in the simulation and measurement are caused by both the limits of the measuring technique and the different sizes of the probe. It is because CST Studio has integrated custom probes that are suitable for similar types of tasks. There is also a slit effect from 2 GHz, and at higher frequencies, there is a periodic decrease and increase in shielding efficiency. A similar event occurred in variant A. The measurement uncertainty is approximately 0.3 V/m for frequencies up to 1 GHz, 0.1 V/m for frequencies 1 GHz to 2 GHz, and 0.35 V/m for frequencies higher than 2 GHz.

6.5 Experiment – Coaxial Line

The next sub-experiment describes the search for a threshold where significant changes occur when the mesh of the shielding grid is disturbed. This topic has already been mentioned in the chapters on the current state and introduction of the experimental part. However, in these cases, it describes only the effects of mesh size or quantity on the quality of shielding. This experiment should be based on shielding A, which appears to be ideal. Cover B is similar to the issue mentioned above and using measuring techniques; it would be more challenging to identify minor changes. A coaxial line terminated with two conductors, and a vector analyzer was used for practical measurements. The material was inserted between the conductors, and a thin sheet of insulating material prevented contact. Subsequently, minor changes in the grid structure, which may occur during the installation of the cover or its use, were tested. The changes in the structure corresponded to those made in the simulation environment. The GTEM chamber model could not be used for this experiment because identifying the changes would be impossible. Hence, a new coaxial line model had to be made, and the results that were the basis for optimization were compared.

Measuring equipment

- Rohde & Schwarz ZND Vector network analyzers (100 kHz–4.5 GHz)
- Conductors
- RF cables

6.6 Results – Coaxial Line

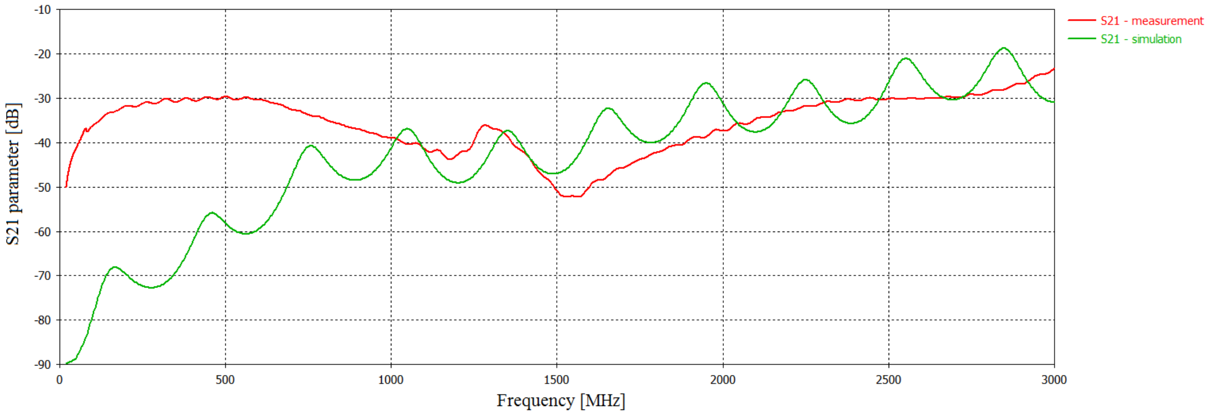

Fig. 8. Comparison of simulation and measurement with Coaxial Line.

The differences caused at lower frequencies are due to coaxial lines designed for operating frequencies from 700 MHz. Differences at higher frequencies can be caused by deviations of technical parameters in simulations from actual values. The expected deviation will be a brass conductor, which has oxidized slightly over the years and was difficult to imitate its current composition.

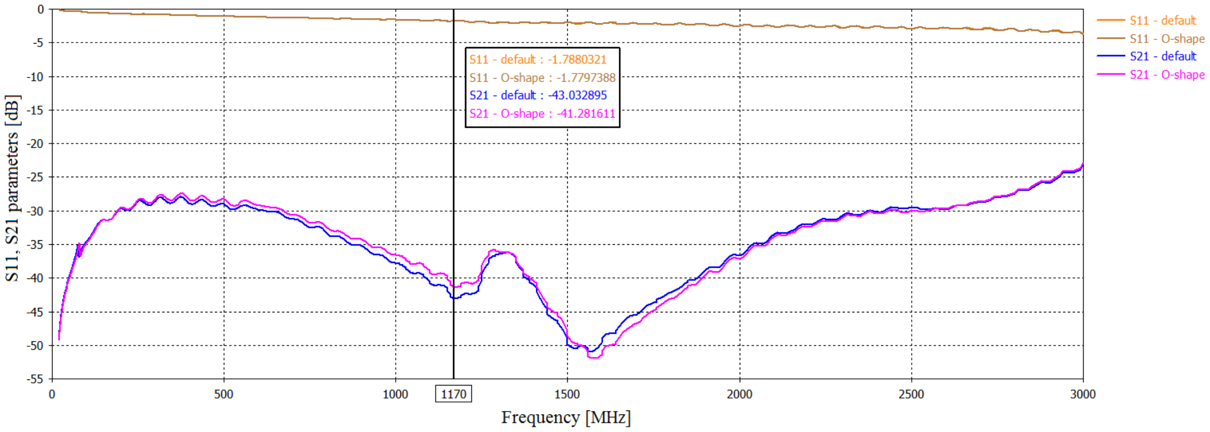

Fig. 9. Measured S11 and S21 Parameters for Maximal Grid Disruption.

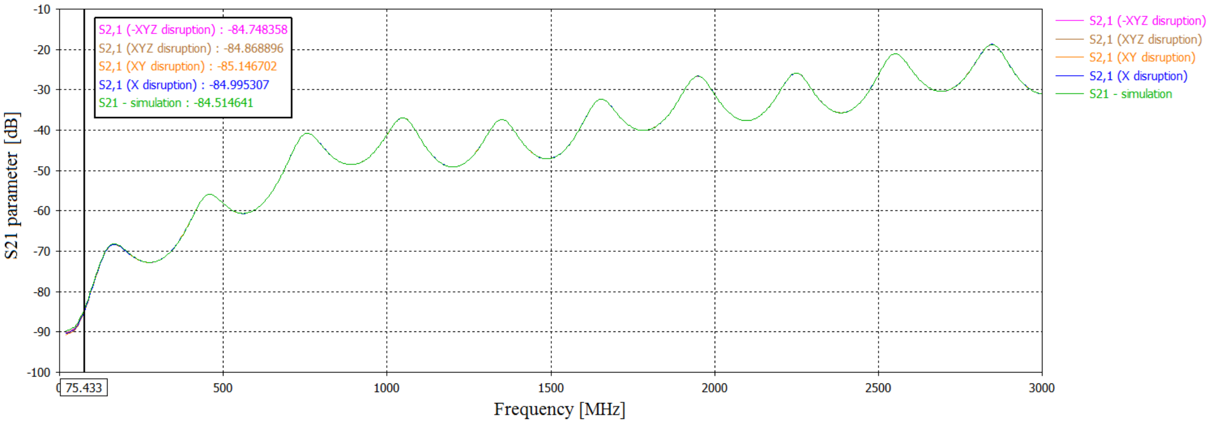

Fig. 10. Simulated S21 parameter for Different Grid Disruptions.

The experiment revealed that disruption of the shielding grid would cause a negligible decrease in shielding efficiency. Adjusting the mesh size of the original material was complicated, and minor changes were difficult to make. The material was often destroyed. The maximum change to "O" shape in the x, y, and z axes was approximately 3 mm. The simulations did not suffer from the problem of material destruction, and the change of parameters was more straightforward; the limiting factor was the contact with the adjacent wall of the eye. The results show that the expected findings; no slight change in the structure of the grid will cause a noticeable decrease in shielding. Concerning earlier chapters, a reduction in effectiveness can be expected with a more significant number of holes; however, the experiment revealed that even more holes have no considerable effect.

7. CONTRIBUTION OF WORK TO SCIENCE AND PRACTICE

Security cameras represent one of the crucial factors of physical security, and their reliability has a significant impact on maintaining safety. However, the technology developments have increased electromagnetic interference in recent years, which is why the demand for ensuring the reliability of equipment has increased. Therefore, this work focuses on potential ways to improve the immunity of cameras, which in some cases may suffer from electromagnetic interference, especially in industrial areas.

The benefit of the thesis lies in evolutionary algorithms application into design development. The algorithms using in the field of shielding is a new matter, which was confirmed by a survey of the current state. The limitation lies in the fact that the outputs can be complex to manufacture, so the scales must be set correctly, eventual what the user needs (transparency, shielding). If necessary, adjust the input parameters. However, this innovative approach led to submit an international project regarding the application of evolutionary algorithms to 3D antenna design.

Other advantages of the work are more of a theoretical nature; it is the design of measuring technology in a simulation environment and comparison with reality. In particular, the comparison of the GTEM chamber model with the real one is still a relatively unique matter. Knowledge about the number or size of holes or the effect of faults in the shielding grids can also expand current knowledge in shielding. Currently, there are few publications on electromagnetic shielding of cameras, and this work could help as a basis for future work.

8. CONCLUSION

The thesis aims at the way how to improve electromagnetic immunity of security cameras. The work is divided into several parts deal with theoretical background, current state, experiment, and finally, results.

The current state discusses the security cameras regarding electromagnetic compatibility. Unfortunately, not many papers are devoted to this topic, although it is an interesting problem from both a scientific and an industrial point of view. Unlike other devices, cameras are an exciting product because the creation of a shield is not accessible due to the part of the lens. Currently, many materials provide relatively high transparency and, at the same time, acceptable shielding effectiveness. However, these materials often bring many limits in terms of price or lower efficiency. A more efficient solution is offered by classic metallic materials, which unfortunately do not provide the required transparency. The answer can be metal grids, which are an impressive compromise and, at the same time, the output of the practical part of the work.

The experimental part begins with the application of evolutionary algorithms to the design of the shielding grid. Based on the input parameters, the algorithm seeks the optimal solution. There are several different algorithms with different successes. The limit of the resulting designs was the complicated production of test prototypes, so for further research, commercially available materials were used, which were used for the creation of new shielding covers. These covers were modeled using the simulation software CST Microwave Studio, and then the results of simulations and practical measurements were compared.

The conclusion of the work is devoted to testing the shielding grid disruption and finding the threshold, after which there is a significant decrease in shielding properties. This experiment was performed in a simulation environment and real laboratory conditions with the help of coaxial lines.

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