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Low Frequency Electromagnetic Interferences Impact on Transport Security Systems Used in Wide Transport Areas

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ABSTRACT: The article presents the impact of electromagnetic interferences of low frequency range, on transport security systems used in wide transport areas. Intended and unintended (stationary and mobile), electromagnetic interferences, impacting on items and components constituting transport system at wide area (seaport, railway, etc.), cause changes of its vulnerability, resistance and durability. Diagnostics of interferences sources (amplitude, frequency range, radiation characteristics, etc.), appearing within transport environment, and usage of appropriate technical solutions of systems (i.e. shielding, reliability structures), allows for safe implementation of safety surveillance of human beings, properties and communication means.

1 INTRODUCTION

Transport security systems are highly equipped with different kinds of appliances, that are subject of continuous miniaturization, caused by rapid evolution taking place in the field of electronics. The appliances are used in stationary and mobile objects, i.e. fire detection systems (microprocessor detectors, control panels, power modules). Electronic components and systems operate under lower voltage supply and reduced power consumption.

Therefore, electromagnetic fields of lower intensity, can interfere with electronic devices, causing disruptions in transport security systems functionality, or even resulting with their failure – Fig. 1.

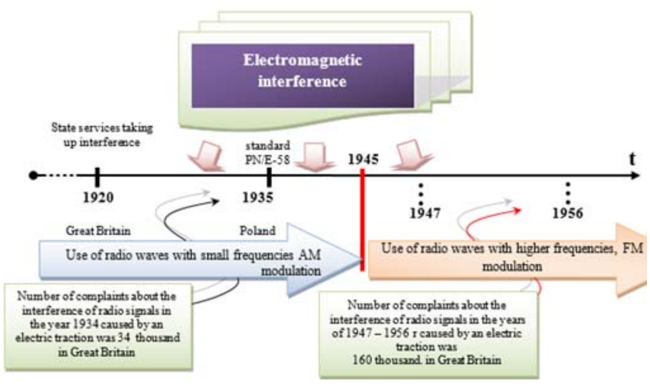

Figure 1. Electromagnetic interferences in a railway area

Following safety states of transport security systems can be distinguished, taking into account the impact of interferences [Dyduch & Paś & Rosiński 2011, Paś 2015b, Rosiński 2015a]:

1 transport security system not affected by inside and outside interferences – the intensity of interferences too low, their permitted level not

exceeded, the system stay in its actual operation state;

2 the appliances, operating within transport security systems, automatically compensate interferences by means of passive or active filters, or other devices securing their functionality;

3 the appearance of interferences causes transition of transport security system, from the state of full operational ability, into the state of restricted operational ability – return to the full ability state demands intervention of service [Rosiński 2015b, Siergiejczyk & Paś & Rosiński 2016, Siergiejczyk & Paś & Rosiński 2015];

4 the appearance of electromagnetic interferences within transport security system results with its partial or complete damage – state of unreliability of safety.

To analyse electromagnetic interferences influence on transport security systems, following criteria should be taken into account:

– system's resistance to interferences, defined as ability to continue proper functionality of its appliances, under interferences appearance;
– system's susceptibility to interferences – meaning response of functioning system to inside and outside interferences;
– system's durability to interferences – understood as its ability to maintain initial conditions until interferences discontinue.

According to European Directive 89/336/EEC, concerning electromagnetic compatibility, all components of transport security systems should ensure appropriate level of resistance to interferences, allowing them to maintain proper functionality in particular electromagnetic environment [Ott 2009]. This applies not only to electronic security systems, but also to others, that are built of electronic components [Krzykowska & Siergiejczyk & Rosiński 2015, Siergiejczyk & Krzykowska & Rosiński 2015a, Siergiejczyk & Krzykowska & Rosiński 2015b, Siergiejczyk & Rosiński & Dziula & Krzykowska 2015, Weintrit & Dziula & Siergiejczyk & Rosiński 2015].

Transport security systems, used on the vast areas, usually operate in hard conditions, caused by fluctuations of air temperature and humidity, precipitation, climate changes, water intrusion, vibrations [Burdzik & Konieczny & Figlus 2013], service abilities [Laskowski & Łubkowski & Pawlak & Stańczyk 2015]. Sources of intentional electromagnetic fields appearing in ports and aboard ships (radar and radio-navigational stations, stationary and mobile radio-communication stations, etc. [Kaniewski & Lesnik & Susek & Serafin 2015, Paszek & Kaniewski 2016]) and of non-intentional ones (industry power supplies, generators and electric engines, power cables and lines, etc.), are contributing to formation of an "electromagnetic smog", able to decrease working conditions of components of security systems, and also other ICT systems [Kasprzyk & Rychlicki 2014, Lewiński & Perzyński & Toruń 2012, Sumiła & Miszkiewicz 2015]. The quality of information does also mean, in case of mentioned exploitation conditions [Stawowy 2015, Stawowy & Dziula 2015]. Transport security systems, operating in hard environmental conditions, should meet the requirements, specified in respective regulations concerning their exploitation.

The exploitation phase of the transport security systems includes co-existing of minimum three below mentioned processes:

1 **the exploitation process**, which aim is to perform required utility task, meaning to result with expected exploitation effect;

2 **the destruction process**, resulting with reducing of utility properties of electronic security systems, i.e. disruptions of information flow process at wireless sensors, caused by electromagnetic disruptions, existing in the environment. Following kinds of the destruction processes can be distinguished:
   – overt destruction process,
   – hidden destruction process

3 **the anti-destruction process**, covering information collecting, and all other activities delaying or stopping the destruction process, and recovering its effects within subsequent phases of the destruction process evolution (the "therapy").

Electronic security systems are impacted by external - $\gamma_z(t)$, and internal interferences - $\gamma_w(t)$, generated within wide area, described by random process S(t). When level of interferences S(t) exceeds allowed value $S_d(t)$ (allowed level specified for the security system), failure of the system takes place.

Time of the electronic security system functioning, until the failure takes place, can be assumed as one having exponential distribution, if:

– external - $\gamma_z(t)$, and internal - $\gamma_w(t)$ interferences are asymptotically independent, meaning $\gamma_z(t_2)$ does not depend on $\gamma_z(t_1)$, and $\gamma_w(t_2)$ does not depend on $\gamma_w(t_1)$;
– relations between $\gamma_z(t_1)$ and $\gamma_z(t_2)$, and $\gamma_w(t_1)$ and $\gamma_w(t_2)$, decrease with simultaneous increase of:

  $\tau' = t_2' - t_1'$, for $\gamma_z(t)$;

  $\tau'' = t_2'' - t_1''$, for $\gamma_w(t)$ – Fig. 2;

– external - $\gamma_z(t)$, and internal - $\gamma_w(t)$ interferences do not show certain tendencies, meaning their peak values appearances are random, and can not be predicted, thus, interferences $\gamma_z(t)$ and $\gamma_w(t)$ are stationary.

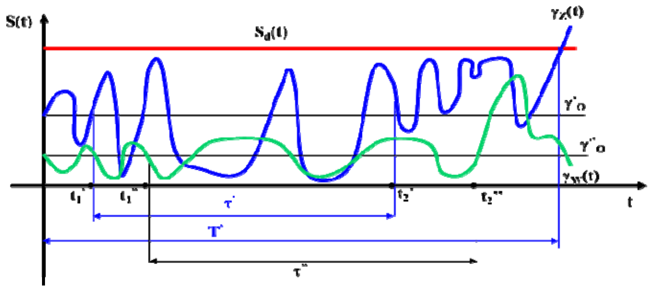

Figure. 2. The progress of impact of external - $\gamma_z(t)$, and internal - $\gamma_w(t)$ interferences generated within wide transport area, allowed level value of interferences $S_d(t) = S_d$ does not depend on time; the system defect appears not as cumulating of its internal technical parameters, but rather as a result of impact of external and internal interferences, that exceed allowed level, defect of the system is caused by interferences level only

When projecting transport security systems, it is necessary to consider environmental conditions of transport system's area, and select appropriate appliances, that are going to be included in the systems (i.e. power supplies [Rosiński 2015c]). To meet the requirements concerning electromagnetic compatibility, for proper project works on transport security systems, it is necessary to investigate electromagnetic environment within particular area [Paś & Siergiejczyk 2016, Siergiejczyk & Paś & Rosiński 2015, Siergiejczyk & Rosiński & Paś 2016].

To determine indicators of interferences influence on transport security systems, within the area of electromagnetic interferences impact, it is required to know characteristics of radiation sources. For this purpose, electromagnetic interferences are divided into two sub-ranges: in regard to frequency range, and following properties of electromagnetic field:
1 the way of propagation of interferences within the transport area;
2 attenuation of propagation of interferences within the transport area;
3 shielding of interferences within the transport area by walls, building and metal partitions of various thickness, vegetation, etc.;
4 impact of interferences on transport security system;
5 the way of protecting against interferences impacting on particular components of transport security systems – Fig. 3;
6 strength of intentional and non-intentional interferences, occurring within restricted transport area.

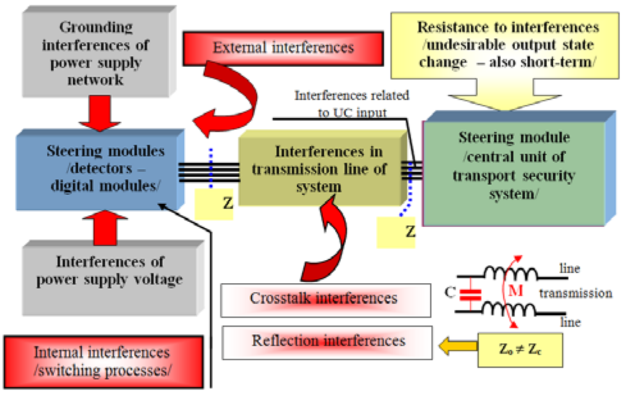

Figure 3. Impact of radio-electric interferences on transport security system: Z_o, Z_c – impedance of power-load and centre, M – factor of inductive coupling, UC – digital device (control panel)

2 TRANSPORT SECURITY SYSTEM CONSISTING OF ONE TRANSMISSION BUS AND MODULES BASED ON RS-485 INTERFACE

The system of above structure is shown in Fig. 4, in distracted version. The modules are connected to the main unit by bus with RS-485 interface. The interface used, enables to connect components of the system at distance up to 1200 metres. The system structure is modular [Rosiński 2008, Rosiński 2011], that can be built of system enhancing modules, controllers, and monitoring and control computer [Duer & Zajkowski & Duer & Paś 2012, Paś 2015a].

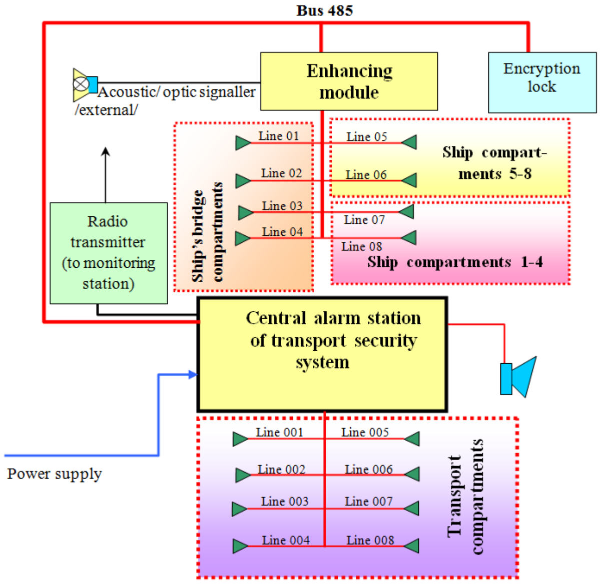

Figure 4. Block diagram of the distracted system, consisting of one transmission bus and modules based of RS-485 interface

Transport security systems are ones, whose purpose is detection of threats appearing within the transport process (for both stationary and mobile objects) [Paś 2015c, Paś 2016]. The usage of the systems, in transport process, increases, and they are supporting safety of [Dziula & Kołowrocki & Soszyńska-Budny 2013]:
1 human beings (i.e. monitoring systems installed in stationary objects of airports, railway stations, ports, etc.);
2 cargo stored in stationary objects (i.e. logistic centres, land and sea cargo handling terminals, etc.);
3 cargo transported by mobile objects (railway, maritime and air transport, where, if supported by GPS system, allow to monitor cargo conditions and track movement of transport means).

Transport security systems function in various climate conditions and various surrounding electromagnetic environment, that can cause occurrence of interferences. Proper functionality of transport security system depends on:
– reliability of particular components, the system is built of;
– internal reliability structure of transport security system;
– undertaken strategy of exploitation of transport security system;
– electromagnetic interferences impacting on system operation process.

3 TRANSPORT SECURITY SYSTEM CONSISTING OF TWO TRANSMISSION BUSES AND MODULES – EXPLOITATION INDICATORS

Fig. 5 shows safety states defined for exploitation process of transport security system, consisting of two transmission buses and modules, in case of impact of electromagnetic interferences. The impact of interferences has been indicated by transition intensity lines γ_z and γ_{1z}. In case of occurrence of electromagnetic interferences of very high level, i.e.

atmospheric discharge (catastrophic event), the system changes state from $R_0(t)$ into $Q_B(t)$ - unreliability of safety.

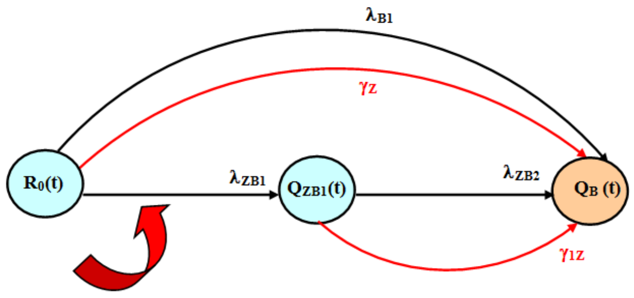

Figure 5. Transport security system consisting of two transmission buses and modules.

The problem of electromagnetic interferences has appeared at the early stage of radio-communication evolution. There were already, before the Second World War, public services involved in interferences, in many countries (i.e. in England – respective service was established in 1920). Rapid evolution of radio-communication and television after 1945, and usage of higher and higher transmission frequencies, caused the number of complaints regarding interferences in England, over the years 1947-1956, increased up to 160 thousand per year (to compare – number of the complaints in 1934 was around 34 thousand). The researches on influence of interferences on radio reception, started in Poland in 1935. Two years later, special services involved in eliminating of interferences, were established. Polish Electric Standard PN/E-58: „Recommendations for eliminating of interferences within radio reception, caused by different electric devices", was issued in 1935. Actually, within transport area, analogue and digital electronic equipment is used, that themselves, during operation, emit non-intentional electromagnetic field, and is also exposed to external fields emitted by external devices.

The system shown in Fig. 5 can be described by following Chapman – Kolmogorov equations:

$$R_0'(t) = -\lambda_{B1} \cdot R_0(t) - \gamma_Z \cdot R_0(t) - \lambda_{ZB1} \cdot R_0(t)$$
$$Q'_{ZB1}(t) = \lambda_{ZB1} \cdot R_0(t) - \lambda_{ZB2} \cdot Q_{ZB1}(t) - \gamma_{1Z} \cdot Q_{ZB1}(t)$$
$$Q'_B(t) = \lambda_{B1} \cdot R_0(t) + \gamma_Z \cdot R_0(t) + \gamma_{1Z} \cdot Q_{ZB1}(t) + \lambda_{ZB2} \cdot Q_{ZB1}(t)$$

Assuming initial conditions:

$$R_0(t) = 1$$

$$Q_{ZB1}(0) = Q_B(0) = 0$$

And by means of Laplace transform, following linear set of equations is obtained:

$$s \cdot R_0^{*}(s) - 1 = -\lambda_{B1} \cdot R_0^{*}(s) - \gamma_Z \cdot R_0^{*}(s) - \lambda_{ZB1} \cdot R_0^{*}(s)$$

$$s \cdot Q^{*}_{ZB1}(s) = \lambda_{ZB1} \cdot R_0^{*}(s) - \lambda_{ZB2} \cdot Q^{*}_{ZB1}(s) - \gamma_{1Z} \cdot Q^{*}_{ZB1}(s)$$

$$s \cdot Q^{*}_B(t) = \lambda_{B1} \cdot R^{*}_0(s) + \gamma_Z \cdot R^{*}_0(s) + \gamma_{1Z} \cdot Q^{*}_{ZB1}(s) + \lambda_{ZB2} \cdot Q^{*}_{ZB1}(s)$$

Then, by means of schematic approach:

$$(R_0, Q_{ZB1}, Q_B) \rightarrow \begin{bmatrix} \dfrac{1}{a} \\ \dfrac{\lambda_{ZB1}}{b \cdot a} \\ \dfrac{\lambda_{B1} \cdot b + \gamma_{1Z} \cdot \lambda_{ZB1} + \lambda_{ZB2} \cdot \lambda_{ZB1}}{s \cdot a \cdot b} \end{bmatrix}$$

where:

$$a = s + \lambda_{ZB1} + \gamma_Z + \lambda_{B1}$$

$$b = s + \lambda_{ZB2} + \gamma_{1Z}$$

Marks „*" and „s", associated with probabilities of system stay at particular safety states R_0, Q_{ZB1}, and Q_B, have been skipped when forming final above result.

By means of the inverse transform, following results are obtained:

$$R_0(t) = e^{-(\lambda_{ZB1} + \gamma_Z + \lambda_{B1}) \cdot t}$$

$$Q_{ZB1}(t) = \lambda_{ZB1} \cdot \left[\frac{\exp[-(\lambda_{B1} + \gamma_Z + \lambda_{ZB1}) \cdot t] - \exp[-(\lambda_{ZB2} + \gamma_{1Z}) \cdot t]}{(\lambda_{B1} + \gamma_Z + \lambda_{ZB1} - \lambda_{ZB2} - \gamma_{1Z})} \right]$$

$$Q_B(t) = \left[\begin{array}{l} \dfrac{\lambda_{ZB1} \cdot \lambda_{ZB2} + \lambda_{B1}\lambda_{ZB2} + \lambda_{ZB1} \cdot \gamma_{1Z}}{(\lambda_{B1} + \lambda_{ZB1}) \cdot (\lambda_{ZB2} + \gamma_{1Z})} + \lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \\ \cdot \left[\dfrac{\exp[-(\lambda_{B1} + \lambda_{ZB1}) \cdot t] - \exp[-(\lambda_{ZB2} + \gamma_{1Z}) \cdot t]}{(\lambda_{B1} + \lambda_{ZB1}) \cdot (\lambda_{B1} + \lambda_{ZB2} - \lambda_{ZB1} - \gamma_{1Z})} \right] + \\ + \lambda_{B1} \cdot \left[\dfrac{\begin{array}{l} \exp[-(\lambda_{B1} + \lambda_{ZB1}) \cdot t] \cdot \lambda_{ZB2} - \exp[-(\lambda_{B1} + \lambda_{ZB1}) \cdot t] \cdot \\ \cdot \lambda_{B1} - \exp[-(\lambda_{B1} + \lambda_{ZB1}) \cdot t] \cdot \lambda_{ZB1} \end{array}}{(\lambda_{B1} + \lambda_{ZB1}) \cdot (\lambda_{B1} + \lambda_{ZB1} - \lambda_{ZB2} - \gamma_{1Z})} \right] + \\ + \lambda_{ZB1} \cdot \gamma_{1Z} \cdot \left[\dfrac{\exp[-(\lambda_{B1} + \lambda_{ZB1}) \cdot t]}{(\lambda_{B1} + \lambda_{ZB1}) \cdot (\lambda_{B1} + \lambda_{ZB1} - \lambda_{ZB2} - \gamma_{1Z})} \right] + \\ + \gamma_{1Z} \cdot \left[\dfrac{\lambda_{B1} \cdot \exp[-(\lambda_{ZB2} + \gamma_{1Z}) \cdot t] - \lambda_{ZB1} \cdot \exp[-(\lambda_{ZB1} + \gamma_{1Z}) \cdot t]}{(\lambda_{B1} + \lambda_{ZB1}) \cdot (-\lambda_{B1} + \lambda_{ZB2} + \gamma_{1Z} - \lambda_{ZB1})} \right] \end{array} \right]$$

4 INFLUENCE OF INTERFERENCES ON TRANSPORT SECURITY SYSTEMS – CERTAIN OPERATION STATES

The influence of electromagnetic interferences on transport security system results with change of probability value of the state of full operational ability $R_0(t_b)$ – Fig. 6. Increase of interferences level (amplitude), results with change of $R_0(t_b)$ parameter value. I.e. for parallel system reliability structure, $R_0(t_b)$ decreases linearly, obtaining zero value for indicator γ=1 (occurrence of electromagnetic interferences of high amplitude, resulting with catastrophic failure – induction of overvoltage in power supply line, caused by an atmospheric discharge). For series-parallel system reliability structure, increase of interferences level (amplitude) to certain value, does not result with change of $R_0(t_b)$ –

electromagnetic interferences of low amplitude, acceptable by system items and components. Increase of interferences level above the certain value, results with rapid decrease of $R_0(t_b)$ value for this structure.

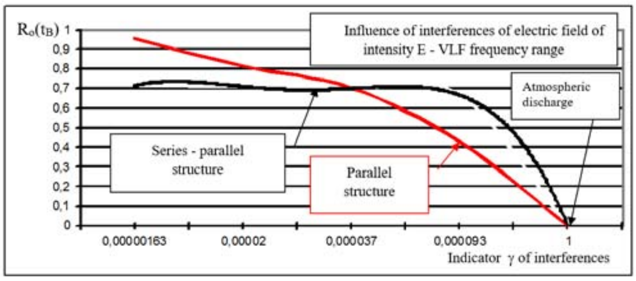

Figure 6. Change of probability value of the state of full operational ability $R_0(t_b)$, under the influence of interferences

Fig. 7 indicates changes of probabilities of the state of full operational ability $R_0(t_b)$, state of restricted operational ability $Q_{ZB1}(t_b)$, and the state of unreliability of safety $Q_B(t_b)$, of the series-parallel transport security system. Transport means, having transport security system installed, are under influence of interferences of different frequency ranges – i.e. interferences of induction B of magnetic field within VLF frequency range (2 – 100 kHz). For determined Γ level of safety of transport security system functionality, meaning system's resistance to mentioned frequency range, equals to 0,05 for the function $R_0(t_b)$ leaning. The Γ level of safety of transport security system functionality, is permissible value of the amplitude of interferences, which is function of: frequency range of interferences, spectrum of interferences, amplitude of interferences, values of particular components of electromagnetic field – magnetic or electric field. Increase of level (amplitude) of interferences γ, results with the decrease of function $R_0(t_b)$ value. While the increase of values of functions $Q_{ZB1}(t)$ and $Q_B(t)$ takes place. Similar character of changes of parameters of probability functions of safety states, takes place for the system having parallel reliability structure – Fig. 8.

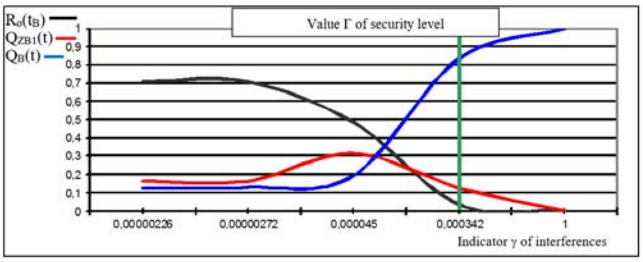

Figure. 7. Changes of probabilities of the state of full operational ability $R_0(t_b)$, state of restricted operational ability $Q_{ZB1}(t_b)$, and the state of unreliability of safety $Q_B(t_b)$, for the transport security system having series-parallel reliability structure (impact of interferences - induction B of magnetic field within VLF frequency range)

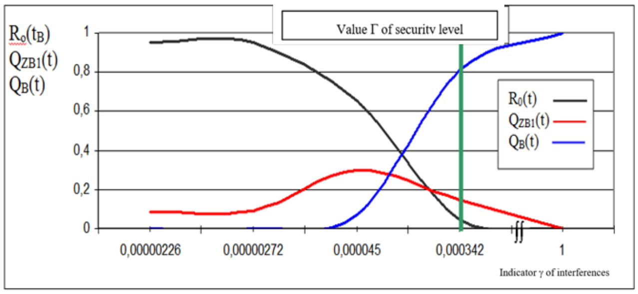

Figure. 8. Changes of probabilities of the state of full operational ability $R_0(t_b)$, state of restricted operational ability $Q_{ZB1}(t_b)$, and the state of unreliability of safety $Q_B(t_b)$, for the transport security system having parallel reliability structure (impact of interferences - induction B of magnetic field within VLF frequency range)

The character of changes of functions of unreliability of safety $Q_B(t)$, and of the state of restricted operational ability $Q_{ZB1}(t)$, of the transport security system having series-parallel reliability structure, has been shown in Fig. 9.

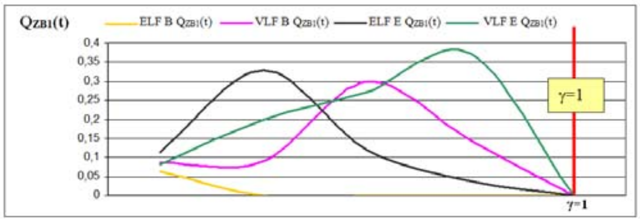

Figure. 9. Changes of probability values of the state of restricted operational ability $Q_{ZB1}(t)$, of the transport security system having series-parallel reliability structure (impact of interferences of ELF (5-2000 Hz) frequency range, and VLF (2-100 kHz) frequency range)

Transport security system is most resistant to interferences of VLF frequency range – both magnetic and electric field components. For the indicator of interferences γ = 1 value (interferences caused by signal of very high amplitude – catastrophic failure), all functions determining unreliability of safety of transport security system reach $Q_B(t) = 1$ value. Values of probability of the state of restricted operational ability $Q_{ZB1}(t)$, for the system of series-parallel reliability structure, for the indicator γ = 1 value, also reach the zero level.

5 CONCLUSIONS

Basing on analysis performed in the article, following conclusions and observations are specified:

– the value of indicator of the safety level (meaning resistance to interferences), of the transport security system, in case of impacting electromagnetic interferences, from certain frequency range, depends on chosen reliability structure of items and components the system is built of – series, parallel, series-parallel, etc., the structures are also influencing on safety and reliability of the system;
– the highest value of reliability indicator RS, and resistance to interferences, is ensured by transport security system having parallel structure, with control centres concentrated, or spread;

- electromagnetic interferences impacting on transport security system, that is used within wide transport area, result with increase of the system electronic components failure intensities, independently of reliability structure, induced, radiated or conducted interferences cause unintended increase of i.e. power supply voltage, change of the operation point of an active item, increase of non-linear distortions, etc.;
- transport security system having series structure is the most vulnerable one to interferences;
- transport security systems installed within wide areas, in case of interferences, are having the lowest value of intended operating time, because the electromagnetic interferences are not damped by building structures;
- transport security systems installed inside buildings, located within transport areas, are less vulnerable to interferences, due to shielding influence of i.e. lightning grids, reinforced concretes, walls, metal roof covers – Fig. 10;

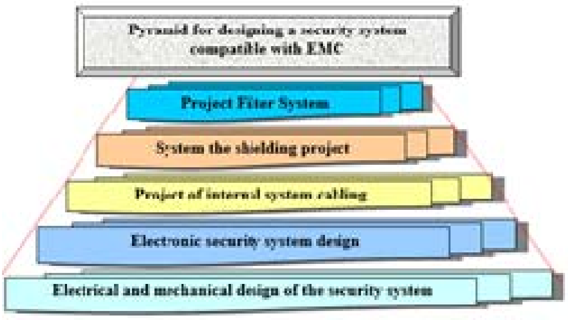

Figure. 10. The pyramid of electronic security system projecting basing on EMC

- the value of resistance to electromagnetic interferences, of transport security system located inside buildings within wide transport areas, depends on the size of a lightning grid spacing (especially in case of interferences of low frequencies);
- values of particular probabilities of the transport security system stay at the operation states, depend on properties of impacting electromagnetic field, and which component – field vector (electric or magnetic), is dominant;
- the highest influence on probabilities of the system stay at certain operation states, is caused by the B induction of the magnetic field of the frequency range ELF, the damping of the B induction by lightning grid is the lowest one for this frequency range – Fig. 11;

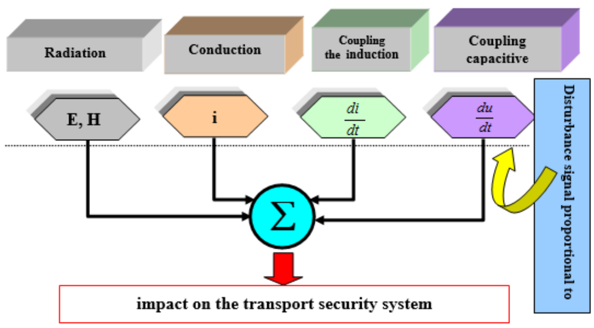

Figure. 11. Mechanism of impact of interferences on electronic security system

- the lowest influence on probabilities of the system stay at certain operation states, is caused by the E intensity of the electric field of the VLF frequency range (2 – 100 kHz). For this electromagnetic field component, values of probabilities R0(t), QZB1(t) and QB(t), reach maximum values for different sources of interferences;
- for low values of amplitude of electromagnetic interferences, impacting on transport security system, the probability function of the system stay at the state of full operational ability, remains at the constant level;
- permissible (limit) levels of interferences influence on transport security system, can be determined by means of resistance indicator, of particular items and components of the system, to certain frequency ranges;
- the permissible level of interferences can be defined as transport security system resistance to impact of electromagnetic interferences of certain frequency range;
- the maximum resistance, of transport security system, to impact of interferences of certain frequency range, depends on minimum resistance of all system items and components, it is built of;
- transport security system resistance depends also on properties of impacting electromagnetic field – if its character is mainly magnetic (E/H < 337 [Ω]) or electric (E/H > 337 [Ω]);
- the level Γ of resistance of transport security system, is the function depending on:
  - properties of electromagnetic field – values of its particular field components E and H for certain frequency ranges;
  - particular items and components of transport security system, having abilities for shielding of electromagnetic interferences;
  - locations of items and components of transport security system – within open area (environment), or in building structures, damping interferences;
  - the lowest value, of the Γ resistance level, of the transport security system appears for the B induction of magnetic field of the ELF frequency range;
- transport security systems, installed within wide transport areas, where an atmospheric discharge takes place, move to the state of unreliability of safety at the moment t0 [Ro(t)=0, QB(t)=1], if there is no counteraction to direct or induced electric impulses (no overvoltage means securing the system);
- in case of installation of overvoltage means and components, potential equalization sources, other available solutions protecting power supply lines, transmission buses, detection zones, etc., of transport security system, there is certain time period, allowing to counteract to consequences of atmospheric discharge (there is then an ability to start so-called emergency process, preventing against failure of whole system or its most important components, i.e. control panel).

The level of safety functioning of electronic security system (resistance to electromagnetic interferences), depends on the system installation location – an open area (i.e. vessel's deck), closed area (vessel's compartments located within her wide area). Values of particular probabilities of the system stay at states $R_0(t)$ and $Q_B(t)$, depend on electromagnetic field properties, range of interferences frequency, dominating vector of electromagnetic field within closest area, character of the system – magnetic or electric, character of the signal – continuous, impulse, modulated, etc.

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