THE ARCHIVES OF TRANSPORT

VOL. XXIII NO 2 2011

10.2478/v10174-011-0009-6

Minimizing the Impact of Electromagnetic Interference Affecting the Control System of Personal Rapid Transit in the Context of the Competitiveness of the Supply Chain

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Received January 2011

Abstract

Personal Rapid Transit control system is exploited in diverse electromagnetic enlivenments. The unintentional or intentional electromagnetic disturbances on a vast railway area can disturb operation of PRT control system. The security systems are responsible for security of humans and goods transpiration and therefore their disturbance can threaten life or health their disturbance can threaten life or health of people exploitation decisions in the reference to these systems. The paper presents the ways of minimization of the influence of electromagnetic disturbances on PRT control system.

Keywords: electromagnetic disturbances, security systems, railway area, PRT control system

1. Introduction

Personal Rapid Transit (PRT) is a zero-emission public transport system working on an individual basis [1]. The system provides transportation "door to door"

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– without intermediate stops with facilities for disabled people. In the project the following assumptions were made:

- ensuring maximum safety of travelers;
- ensuring maximum reliability of the PRT system;
- reducing energy consumption (minimum intensity);
- ergonomics (adapted for the disabled);
- lack of impact of the scheme on the surrounding environment PRT (no emissions from the transport system – such as CO2, noise, vibration, generation of unintentional jamming electromagnetic field).

The fulfillment of these assumptions (especially the first two points) is dependent on the system(s) controlling the PRT. The control system is interfered by electromagnetic interference, whether intentional (e.g., communication systems, radio stations, TV, and others) and unintended (side effect of the electrical signal processing systems, the PRT and the surrounding electrical infrastructure – such as electricity power lines transformer stations) – Figure 1.

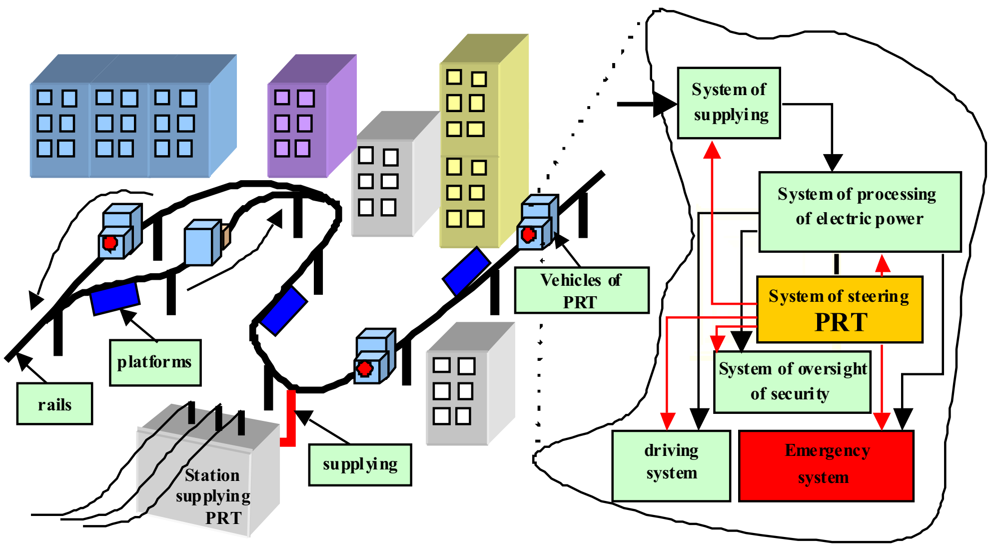


Fig. 1. Infrastructure PRT system – a combination of control system

2. The Impact of Electromagnetic Interference on Control Systems PRT

In the twentieth century, human activities have been introduced artificially in shaping elektroclimate. As a result of the creation of countless sources of radiation there were considerable changes in the Earth's electromagnetic environment. The development of electrical engineering and electronics have led to a myriad of artificial non-ionizing radiation source, emitting a field in a very wide frequency range. Severe requirements have been put on modern electronic control systems used in the SRK, TSN (Transport Surveillance System) and the PRT, among others, miniaturization, reduced power consumption, high reliability [2]. The introduction of these restrictions means that the level of useful signal devices can be comparable to the noise level generated for example by stationary and mobile sources of interference (e.g., base stations, radio, TV, MV lines, high voltage, transformers, electrical equipment in everyday use, the vehicles traction, etc.). Therefore, this important problem is to continuously diagnose the state of the electromagnetic environment for the introduction of new equipment and systems, which rated power is large, such as changing power transformer station, the use of diesel engines for more power in traction, increasing the transmit power stations for mobile telephony. The problem of electromagnetic interference occurred in the early development of radio.

In many countries, even before World War II, there were public servants involved in the disturbances – such as they arose in England as early as 1920. In the prewar period about 10% of complaints related to radio interference urban electric traction. At that time, radios worked on long and medium waves, which created high risk for electromagnetic spectrum of electric traction equipment were. The rapid development of radio and television since 1945, the use of increasingly higher frequencies in broadcasting meant that the number of complaints against interfering in England has increased over the years 1947-1956 to over 160,000 per year (for comparison, in 1934 the number of complaints was about 34,000). However, the number of complaints against interfering with reception by an electric traction has decreased over the years – the reason for this may be the transition to broadcast radio programs on the use of ultra short-wave frequency modulation (FM) broadcasting instead of using amplitude modulation (AM), less resistant to interference [3, 4].

When considering of the impact of disturbance on the PRT and control systems following criteria should be looked at:

- **PRT control system resistance to interference** – defined as the ability to maintain proper operation of equipment during the disturbance;
- **PRT control system susceptibility to interference** – i.e. operating system response to external or internal interference;
- **Resistance of PRT control system to disturbances** – that is, the ability to maintain the primary characteristics of the system after the resolution of interference.

When designing a PRT control system one must take into account the environmental conditions prevailing on "the train" and to choose appropriate devices to include in the system. In order to define them one must know the parameters, characteristics and distributions of various radiation devices which alter the electromagnetic environment on the railway.

In the case of the impact of disturbance on the PRT and control systems, we can distinguish four states of operation of the system:

- control system **does not react** to internal and external interference – noise level is too small, not exceeding the permissible level of interference, the system remains in the operating state in which they are sitting;
- devices included in the PRT control system **automatically eliminate** the interference by passive or active filters and system solutions;
- occurrence of distortion causes PRT control system to go **from the state of full operation to unfitness** – the restoration of fitness requires manual intervention;
- occurrence of distortion in the control system causes damage to the PRT system – total or partial, the system is unusable.

Determination of acceptable conditions of the effect of external electromagnetic fields on the work of electronic devices and equipment containing electronic circuits is defined as electromagnetic compatibility – Figure 2.

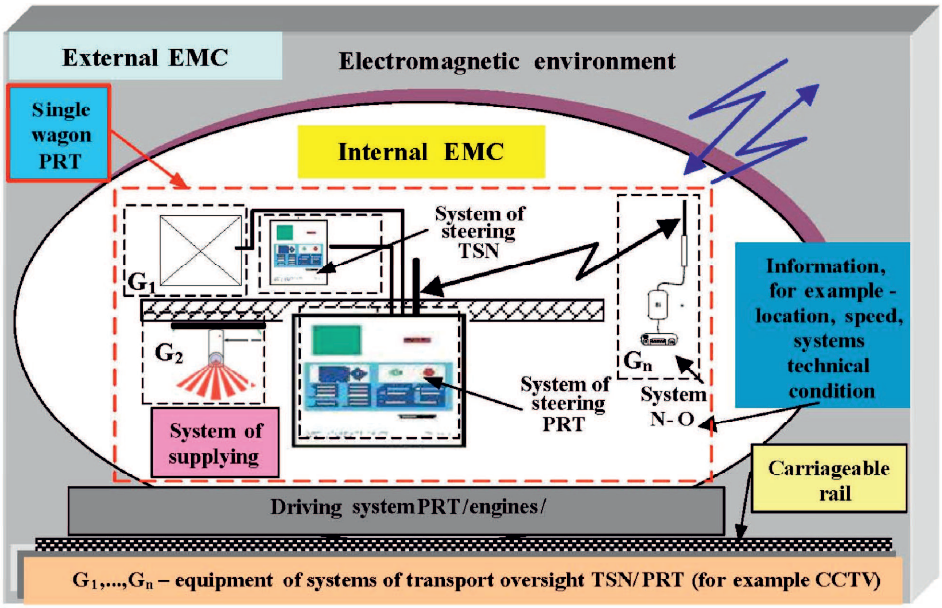


Fig. 2. Electromagnetic compatibility and external and internal control systems PRT

The first definition of this concept comes from the US Department of Defense from 1967. It included the concept of compatibility, the overall design, construction and operations. On this basis, in 1976, the international definition was introduced, the wording of which is almost identical to that cited in the international standard IEC 50 (161) of 1990, later included in the Polish Standard Pr. PN-T-01030.

The norm states ”*electromagnetic compatibility is the ability of a device or system to perform satisfactorily in a specific electromagnetic environment without introducing to this environment unacceptable electromagnetic disturbances*”.

If there are two different systems inside a single PRT wagon, for example SSWiN surveillance system (a system intruder alarm) and control (or power, energy conversion, etc.) then a mechanism of interaction of electromagnetic disturbances of these systems and the electromagnetic environment has been presented Figure 3. Unwanted emission of electromagnetic energy, conveying no useful information, interference and unwanted response systems – are the limiting factor for transmission and processing of information through electrical signals.

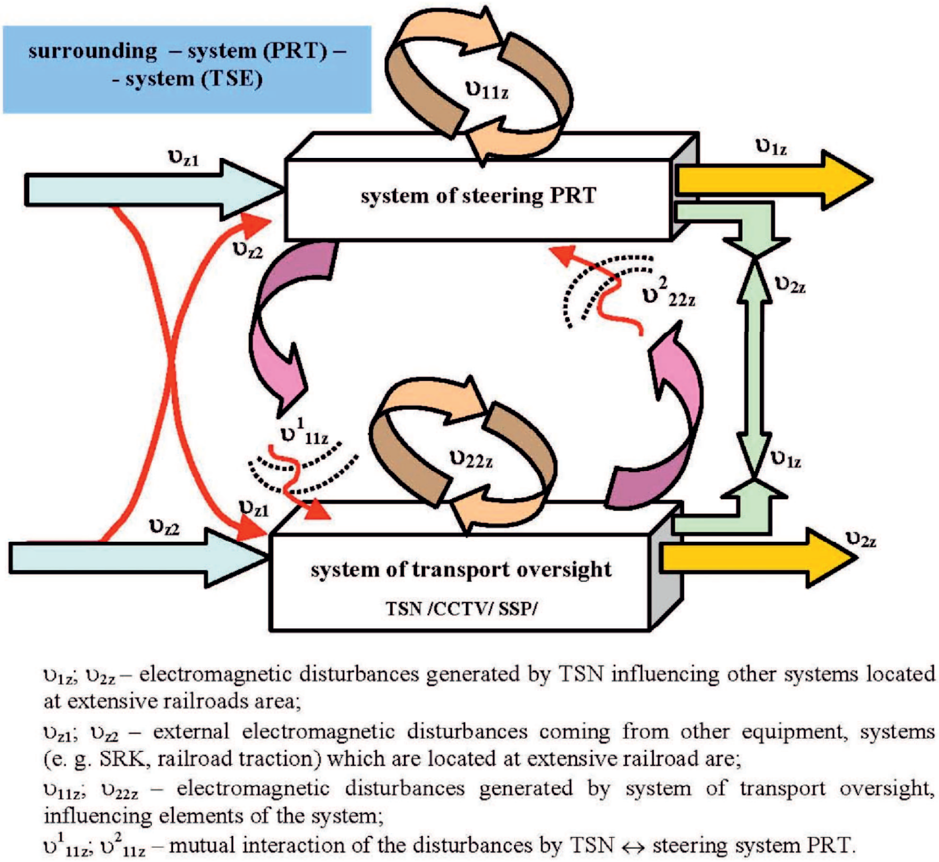
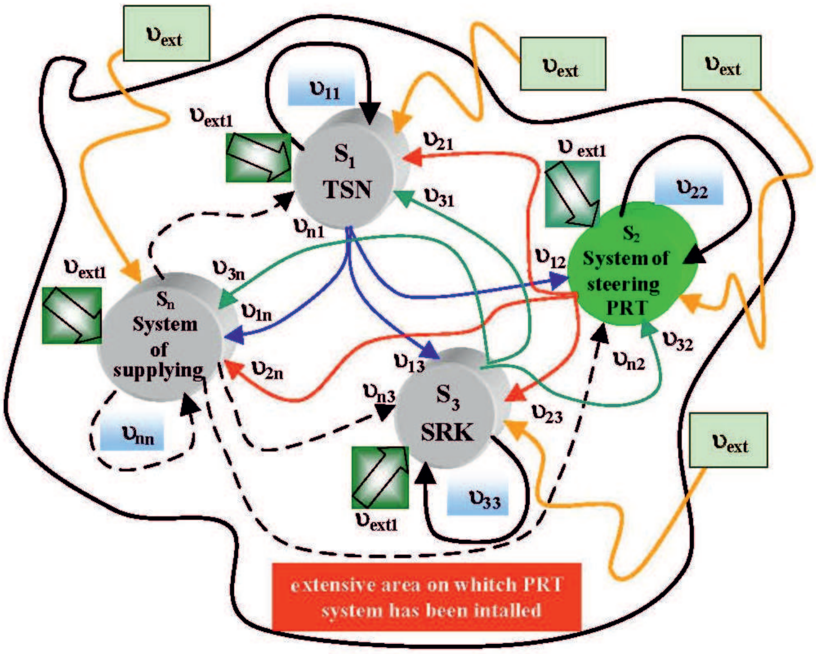


Fig. 3. Mechanism of interaction of electromagnetic systems, PRT, TSN, and electromagnetic environment

The systems can produce undesirable emissions such υ_{11z}; υ_{22z};υ^{1}_{11z}; υ^{2}_{11z} and exhibit undesirable responses such υ_{z1}; υ_{z2} disturbing the normal operation of these systems. For more such concurrent systems – there is a more appropriate ”combination of" interference, where n is the number of systems (including systems PRT), the number of these combinations is $\mathbf{n}^2$ – Figure 4.



υ_1; υ_2;...; υ_n – mutual interaction of the electromagnetic disturbance generated by TSN (system of transport oversight), SRK (system of steering the railway traffic), railroad traction of PRT system and other equipment located atextensive railroad area;

υ_{11}; υ_{22};...; υ_{nn} – electromagnetic disturbance generated within the system – interacting with the elements of the system;

υ_{ext1} – external electromagnetic disturbance generated by other elements, equipment and systems that may be located at extensive railroad area;

υ_{ext} – external electromagnetic disturbance generated by weather discharge; switching processes of electromagnetic networks, terrestrial electromagnetic atmosphere, radar stations, TV broadcast stations, etc. or other radio electric industrial disturbances.

Fig. 4. The mechanism of electromagnetic interference in the case of interaction of n coexisting systems in the vast area of railway ($\mathbf{S}_2$ – PRT control system)

Existing electromagnetic interference in the railway act on PRT control system with following conjugation:

- radiated (range 30 MHz – the amount of distortion proportional to the parameters of the electromagnetic field strength E, i.e. the electric field and magnetic field intensity H);
- conducted – proportional to the value of I [A], disturbing voltage U [V];
- induction (amplitude distortion proportional to the speed of current changes in time);

- capacitive (amplitude distortion proportional to the speed of voltage changes over time) – Figure 5.

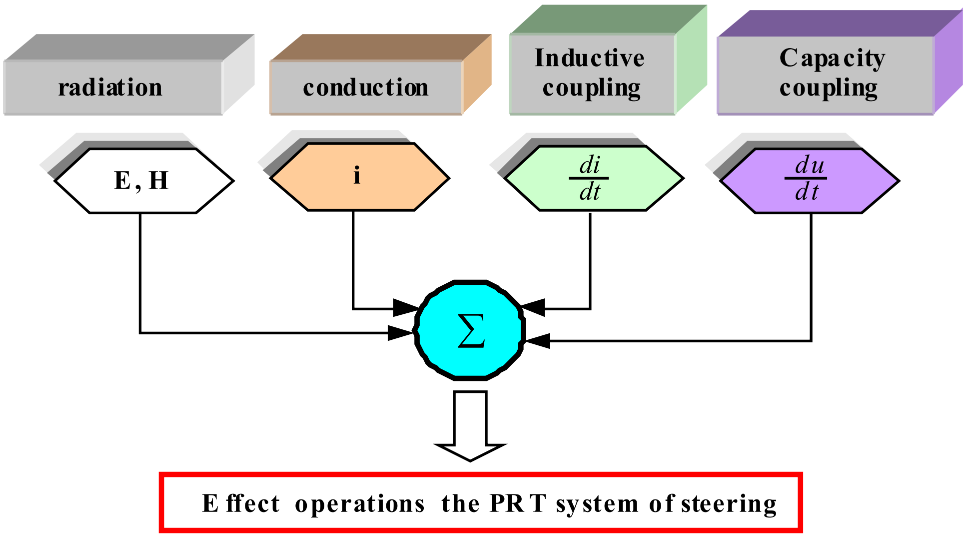


Fig. 5. Mechanism of disturbance of the control system of the PRT

Due to the non linear transient electronic devices (e.g. amplifiers, transformers, active filters, adders, rectifiers, digital electronics, etc.) used in both the PRT control system and other systems installed on the vast area of the railway, electromagnetic interference intermodulation – need to be taken into consideration (Fig. 6).

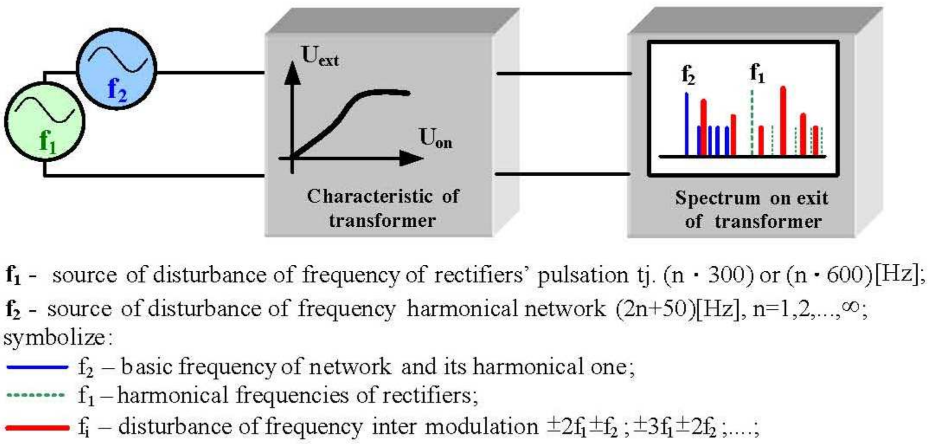


Fig. 6. Intermodulation distortion

Harmonic distortion signal is occurring as a result of its passage through the elements with nonlinear characteristics. In the field of low frequency (signal processing in the system transformer – rectifier), in which the inertia of the nonlinear elements can be neglected, the output – for example the current – can be presented as a function of the input signal (eg voltage) with the development of a power series (element approximation nonlinear)

$$i(t) = a_0 + a_1 U(t) + a_2 U^2(t) + a_3 U^3(t) + ... \tag{1}$$

The coefficient a_1 represents the linear signal processing, while other factors determine the signal distortion. If we assume that amplitude distortions are small compared to the amplitude of the input signal, a power series (1) can be limited to the first three words. Using a forced harmonic signal with frequency f (f = 50 Hz) and amplitude U_m and by limiting the expression for the first three terms, we obtain the equation describing the output signal as a function of time:

$$i(t) \approx a_0 + a_1 U_m \cos 2\pi f t + a_2 U_m^2 \cos^2 2\pi f t + a_3 U_m^3 \cos^3 2\pi f t \tag{2}$$

Pordering the equation against 2πft, we obtain the output spectrum of the form:

$$i = I_0 + I_1 \cos 2\pi f t + I_2 \cos 2\pi 2 f t + I_3 \cos 2\pi 3 f t \tag{3}$$

where:

$$I_0 = a_0 + \frac{1}{2} a_2 U_m^2; \quad I_1 = a_1 U_m + \frac{3}{4} a_3 U_m^3; \quad I_2 = \frac{1}{2} a_2 U_m^2; \quad I_3 = \frac{1}{4} a_3 U_m^3 \tag{4}$$

The amplitude I_n of individual components at frequencies nf determine the harmonic distortion of n-th row. If we use force as a sum of harmonic signals of different frequencies f_1 i f_2 (frequency network signals and distortion rectifiers), the output spectrum will be enriched not only by the second harmonic of the input signal, but also a combination of frequency components for i, j = 1, 2,..... The component combination occurring in the spectrum of the output signal distortion causes distortions called intermodulation. If the amplitude of the harmonics of the input signals are equal and U_{m1} i U_{m2}, the expression describing the output becomes a function of time:

$$i(t) \approx a_0 + a_1(U_{m1} \cos 2\pi f_1 t + U_{m2} \cos 2\pi f_2 t) + a_2(U_{m1} \cos 2\pi f_1 t + U_{m2} \cos 2\pi f_2 t)^2 + \\ + a_3(U_{m1} \cos 2\pi f_1 t + U_{m2} \cos 2\pi f_2 t)^3 \tag{5}$$

Using the formulas short multiplication, and ordering according to the trigonometric equation, the argument of the function harmonic we get:

$$i = I_0 + I_{10} \cos 2\pi f_1 t + I_{01} \cos 2\pi f_2 + I_{20} \cos 2\pi 2 f_1 t + I_{02} \cos 2\pi 2 f_2 t + I_{30} \cos 2\pi 3 f_1 t + \\ + I_{03} \cos 2\pi 3 f_1 t + I_{11}[\cos 2\pi(f_1 - f_2)t + \cos 2\pi(f_1 + f_2)t] + \\ + I_{12}[\cos 2\pi(2f_2 - f_1)t + \cos 2\pi(2f_2 + f_1)t] + I_{21}[\cos 2\pi(2f_1 - f_2)t + \cos 2\pi(2f_1 + f_2)t]$$

The value of i + j = n specifies the intermodulation distortion of the n-th order IMN (Fig. 7).

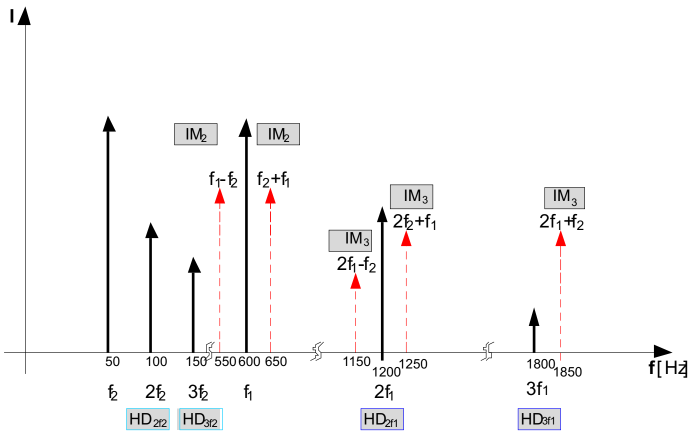


Fig. 7. The value of i + j = n specifies the intermodulation distortion of the n-th order IMN

3. Selected External Sources of Electromagnetic Interference

The PRT railway system will be powered with high voltage power line – 110 or 220 kV. Around the power cables the electromagnetic field is created, that affect systems and inanimate matter – Figure 8. The distribution of magnetic and electric fields produced by the above power lines supplying the PRT system is illustrated in Figures 9 and 10.

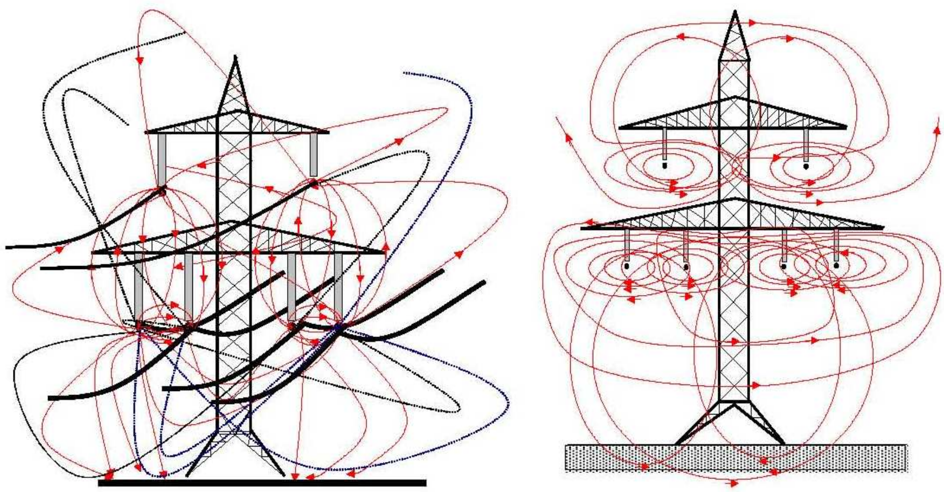


Fig. 8. Distribution of force lines of electric and magnetic fields around power lines powering devices in a large area of railway systems – traction systems – PRT, SRK, TSE

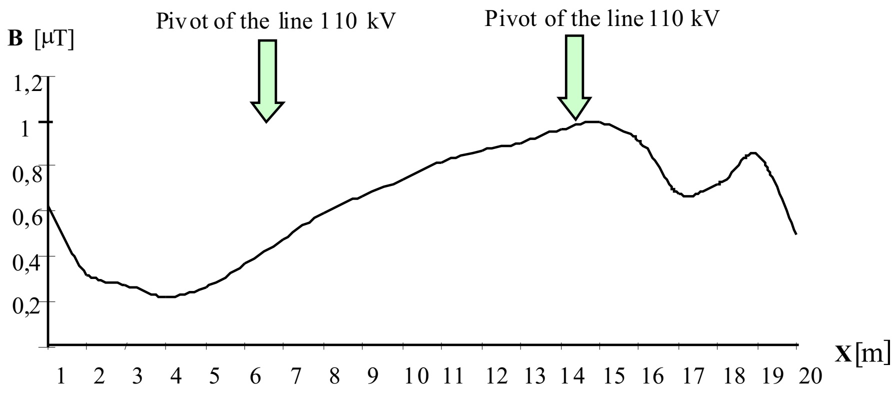


Fig. 9. Distribution of magnetic field lines B [μT] manufactured by the two power lines for railway traction power supply

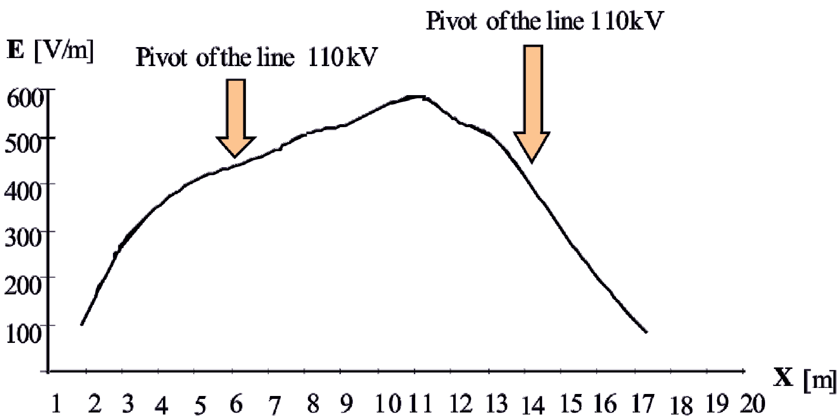


Fig. 10. The distribution of the electric field lines E [V/m], produced by two power lines for railway traction power supply

PRT control systems are equipped with computer monitors to illustrate the operating conditions such as diagnosis, user control and communications. Figure 11 shows the characteristics of radiation generated by a computer monitor control system of the PRT. In Figure 11a,b present the standard ladders (TCO) for an acceptable component of electromagnetic radiation for electric and magnetic fields produced by the PRT system monitors. The spectrum of electromagnetic radiation generated by a computer monitor for a magnetic induction B is shown in Figure 12.

The PRT transport system to maintain a certain temperature in which the controls are operated electric heating uses a different power. Electric heaters are also a source of unintentional electromagnetic field of ELF and VLF frequencies that can interfere with other electronic devices installed in the vehicle PRT system – Fig. 13.

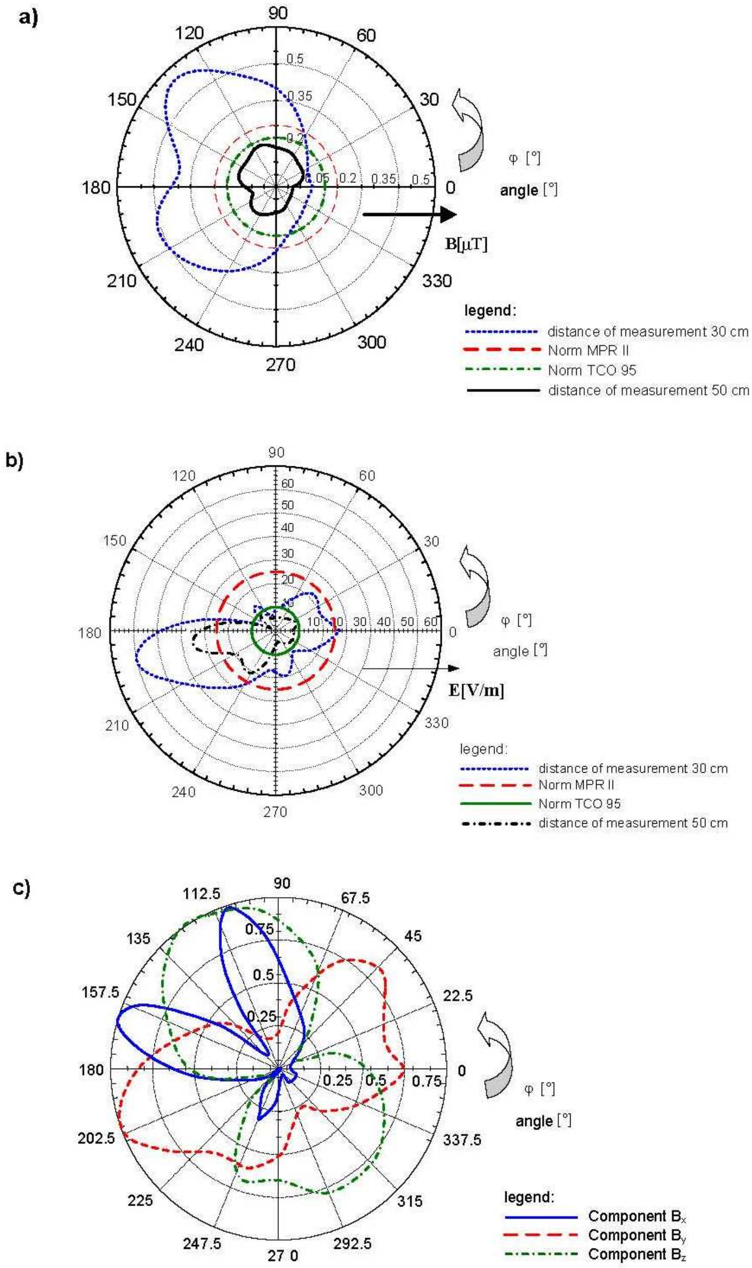


Fig. 11. The characteristics of electromagnetic radiation generated by the monitor control system of PRT, a) characteristics for omni-directional magnetic induction B, b) characteristics for omni-directional electric field intensity E, c) the normalized characteristics of omni-directional components B_x, B_y, B_z [μT] of the magnetic field induction B for the frequency ELF

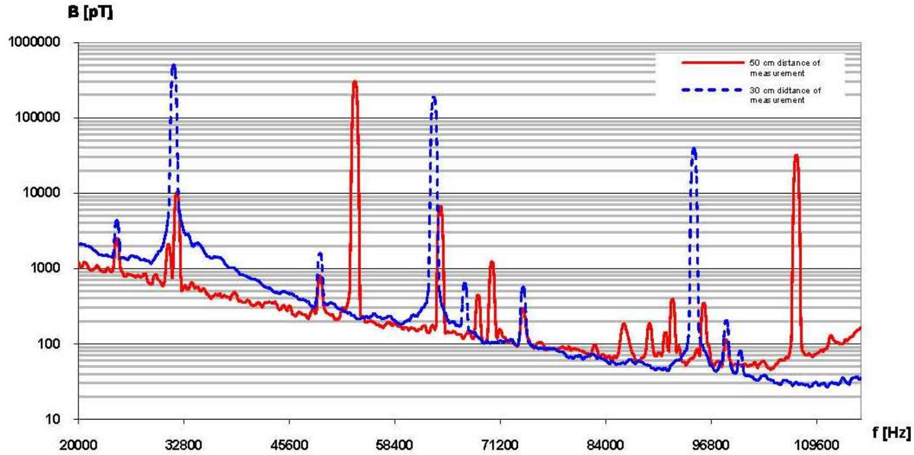


Fig. 12. The Characteristics of electromagnetic radiation generated by the monitor control system of PRT

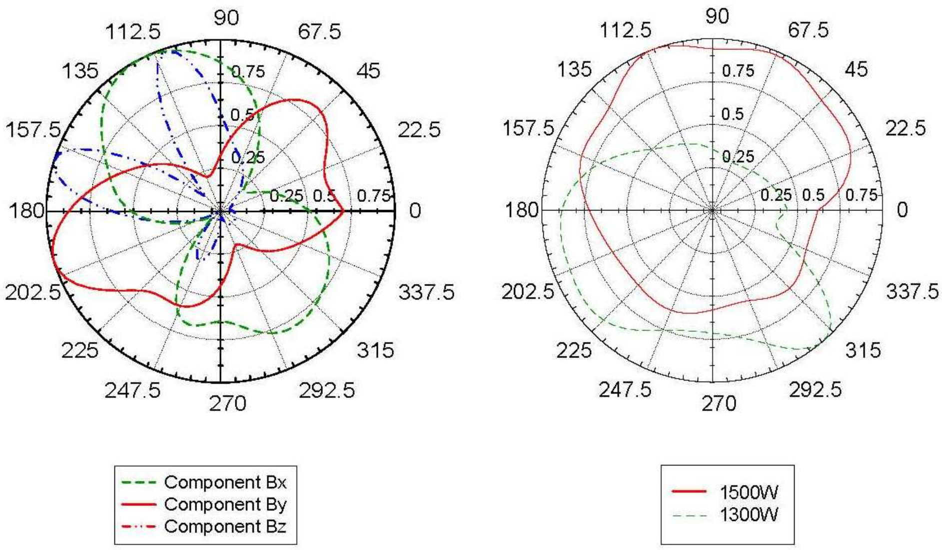


Fig. 13. Left – normalized omni-directional characteristics of components B_x, B_y, B_z [μT] of the magnetic field induction B for the electrical heating unit with a capacity of 1300 W ELF frequency range, Right – omni-directional characteristics normalized induction B [nT] of the magnetic field for the VLF frequency range for the two electric heaters with a capacity of 1500, 1300 W

4. Coupling of Electromagnetic Interference with Control Systems PRT – Selected Issues

Moving the electrical signals from one circuit to another through inductive coupling or capacitive is sometimes called diaphonic or crosstalk. If sensitive and distorting circuits are closed at both ends with the resistance with a value corresponding to the characteristic impedance then they are exploited in fitting conditions. This kind of work is important when working with higher frequencies (e.g., data transmission over short distances with the logic ECL), then transfer the signal (pulse), there will be no reflection – Figure 14.

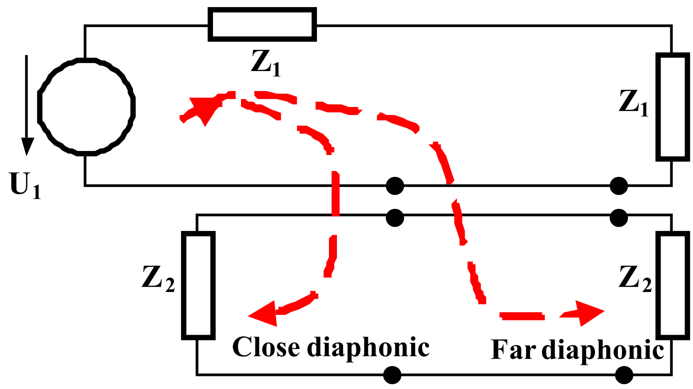


Fig. 14. Diaphonic near and far in systems of information transmission control system PRT

Starting from 400 MHz, interference spread directly through the holes, seal and control system cabinet slots of PRT. For this frequency the wavelength is small enough ($\lambda = 0.75$ m) to find favorable conditions for such spread up. Terms of spreading the (dispersion) interference come from the parameters of holes and current loop between digital systems 1, 2 of PRT control system (Fig. 15). Current loop created in the system is the reason for the emission of electromagnetic interference, for which the electric field can be calculated by the formula 7

$$E = 131 \cdot 10^{-16} \cdot \left(f^2 \cdot A \cdot I\right) \cdot \left(\frac{1}{r}\right) \cdot \sin\Theta \qquad (6)$$

where: f – frequency signal; A – area loop, and – a current circuit, r – distance from the loop; Θ – the angle characterizing the location of the circuit in space.

The way of coupling the input circuit of the control system signals PRT electromagnetic interference is illustrated in Figure 16. Sending information about the state of the control system via radio to the command center to supervise the work of the entire signaling system gives rise to couplings through the holes, culverts of housing system (Fig. 17).

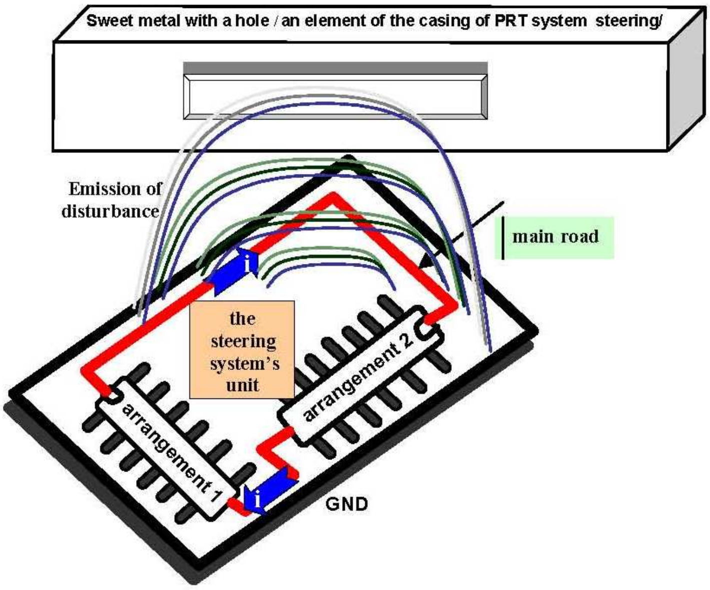


Fig. 15. Emission of interference by the system control room in a housing PRT screening

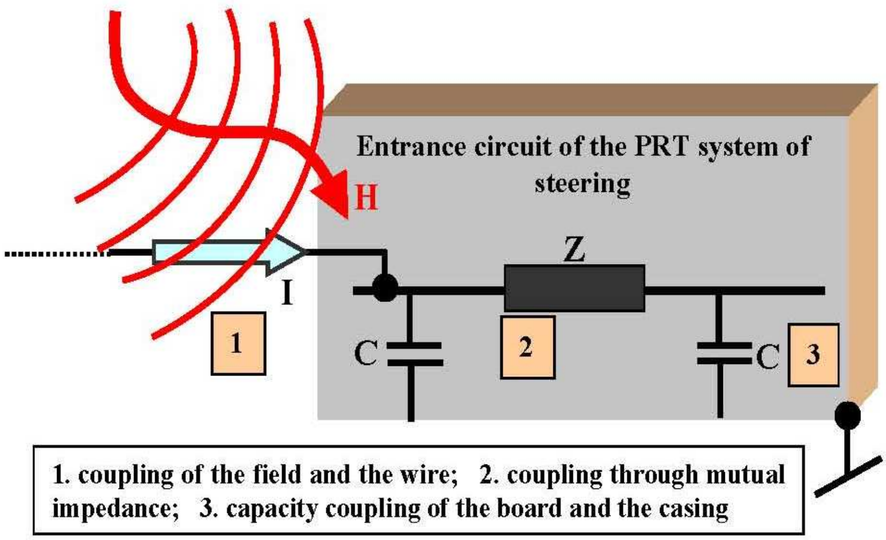


Fig. 16. Coupling the input circuit of the control system signals PRT RFI

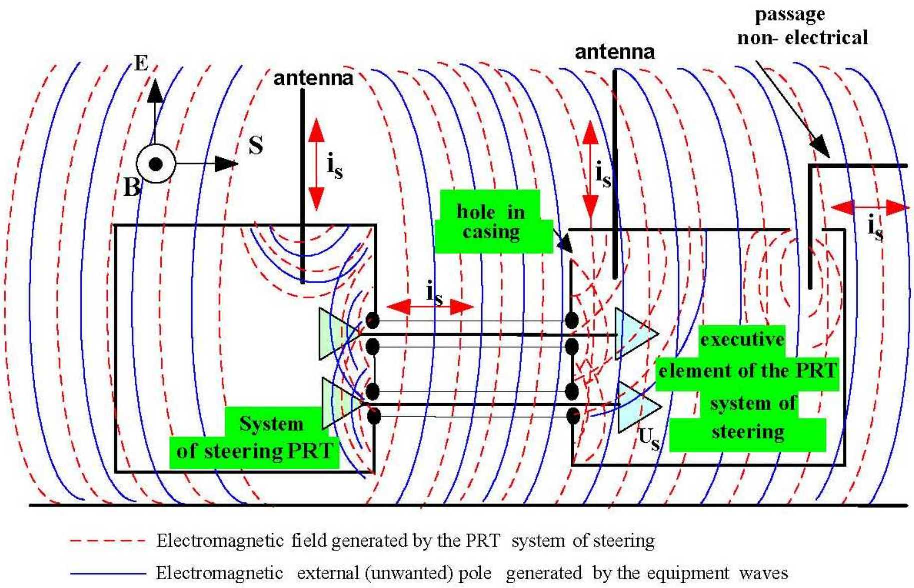


Fig. 17. Feedback control system and actuator during the transmission of information via radio – the use of electromagnetic waves of a certain frequency

5. Conclusions

To determine the effects of electromagnetic interference on the PRT and control systems it is necessary to determine:

- type of engine (s) that is used (power supply with AC or DC, pulse);
- engine power rating P_{max};
- the value of current drawn by motors (fixed, variable, variable 3-phase);
- the value of the motor starting current (in the control of INS 2-3);
- the supply voltage motors (fixed, variable, variable 3-phase);
- allowable voltage drop during start-up (power grid is not designed for heavy loads);
- the value of current / voltage in different states of engine operation (for example, sterile, fixed, short-circuit – the characteristics of the engine speed);
- how to enable / disable the engine (start / stop – transients);
- the way the engine power – for example, shielded cable, power rails, cable diameter, cable length, cross-sectional area, laying of cables);
- parameters of the motor (L, r) L / r – time constant of current rise;
- distribution of diesel engines in the vehicle;

- Engine performance:
  - non-linear magnetic circuit (harmonic);
  - nurseries in the harmonic motor (magnetic circuit);
  - harmonic commutator (switch current);
  - asymmetry relative rotor stator (air gap – stream);
  - manner of motor control – continuous/pulse;
- sources of electromagnetic radiation in the immediate vicinity of the planned investment (electro climate).

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