ALGORITHM FOR AUTOMATIC ADJUSTMENT OF THE RADIO RECEIVER AT ELECTROMAGNETIC ENVIRONMENT USING THE MAXIMUM *SNR* CRITERIA

Constantin Bălan, Ph.D.[1]
Ciprian Răcuciu, Ph.D.[2]
Cornel Ioana, Ph.D.[3]

[1]Fundaţia Lumina – Instituţii de învăţământ,
Şos. Gării Căţelu, Nr. 1R, Sector 3, Bucureşti, România
E-Mail: constantin.balan@lumina.org;

[2]Department of Computer Science,
Titu Maiorescu University, Faculty Science and Information Technology,
Calea Văcăreşti, nr. 187, sector 4, 040441 Bucureşti, Romania,
E-Mail: ciprian.racuciu@gmail.com

[3]Grenoble INP/ENSE3 - GIPSA-lab, Departement Images-Signal
961 rue de la Houille Blanche BP 46, 38402 Saint Martin d'Hères Cedex FRANCE
E-Mail: Cornel.Ioana@gipsa-lab.grenoble-inp.fr

Abstract. *Typically, to adapt the radio receiver at electromagnetic environment, it uses an automatic sensitivity and/or gain control system. They are based on redundant control methods because it does not take into account the probability of disturbance of receiver by the strong perturbations which cause intermodulation products. For intermodulation products to enter the bandwidth occupied by the useful signal must simultaneously fulfill three conditions:*

1. *the random process must to reach the threshold level of the arising intermodulation products;*
2. *the intermodulation products level has to be greater than the receiver sensitivity threshold, so that their energy should not be masked by the internal noise;*
3. *the intermodulation products frequencies have to fall into the useful signal bandwidth.*

The Software Radio (SR) technology allows the implementation of some algorithms using different criteria for the adapting optimization radio receiver at electromagnetic environment. For these reasons we propose that, after establishing the initial conditions, the receiver to be adapted to the electromagnetic environment by using the maximum signal to noise ratio (SNR) criteria. This method does not require the separation of the signal components from the receiver output (useful signal, noises, THD, new spectral components due intermodulation, etc.).

The proposed algorithm takes into account that the initial protection, based on statistical criteria, is redundant, therefore the transfer coefficient value of the attenuator is decremented until the nonlinear effects of receiver are seen at the output. From this point of time, the algorithm seeking the objective function, then the transfer coefficient value of the attenuator remains on hold until there is a significant change in initial conditions.

Keywords: *software radio, electromagnetic environment, analogue front-end, disturbance threshold, dynamic range, optimization criteria, maximum SNR.*

1. INTRODUCTION

In the context of a radio receiver, based on software radio (SR) technology, the signal processing steps, between the antenna and the digital signal processor (DSP), are implemented in the receiver front-end interface. This element contains two components, the analogic front-end and the digital front-end [1,2].

The interface functions are described by the characteristics of the input and output signals. The analog input receives a variety of signals and perturbations from which a band B is selected. As we can observe in the Figure 1, the band B contains several communication channels (N_i channels of band B_i of the service i). This band contains also the target channel, centered on the radiofrequency carrier frequency $f_c = f_{RF}$. Among the signals and perturbations that manifest in the band B, there may be some with a level so high, that it might lead to a nonlinear behavior of the analogic interface and even of the entire receiver.

The interface output should supply a digital signal that is ready to be processed in the base band, with a sampling frequency f_{si}, according to the received waveform. The received diginal signal is the target channel with a band B_i, centered on the carrier frequency $f_c = 0$.

There are different methods of designing a receiver using the SR technology [1, 2], but the aim is to place the Analog to Digital Convertor (ADC) as close to the antenna as possible, minimizing in this way the analogic interface and widening the band of frequencies that is converted to digital.

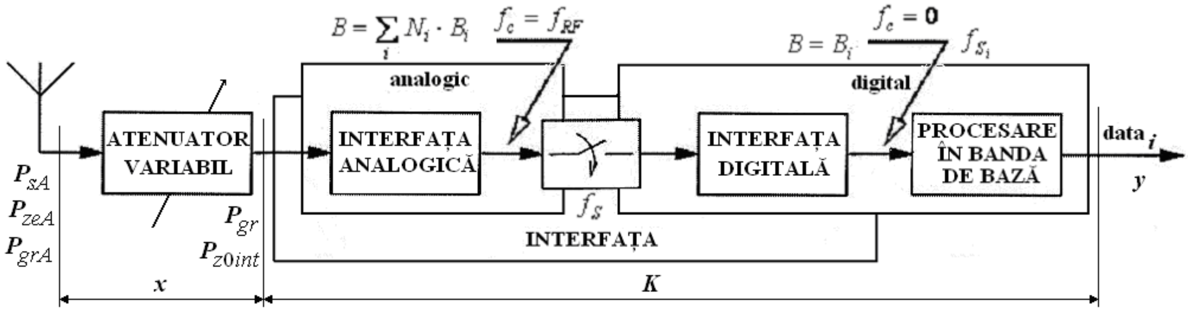

Fig.1 Generalized digital receiver

Regardless of the chosen design, the receiver can manifest false responses caused by insignificant signals or perturbations. From this point of view, the super-heterodyne radio receiver architecture is the most vulnerable because the ***target signal*** is affected by the overall noise at the receiver's input, manifested in its ***passband***, but also by the perturbations that end up in the signal's frequency band, either through additional reception channels: liniar, non-linear or parametric nonliniar, or because of the perturbations frequency coincides with the reception channel's frequency – ***inter-channel perturbations***. The other versions of the receiver's implementation are less vulnerable. In the case of an ideal ***SR*** receiver, false responses are caused only by the non-linear behaviour of the stages within the analog interface. In the case of a direct conversion receiver, false responses are also caused by the parametric non-linear effects that lead to an inverse conversion of the heterodyne's noises under the influence of the perturbations manifested in the preselector's passband.

In order to adapt the receiver to electromagnetic conditions at the reception point, we have to consider both the perturbations that generate fundamental nonlinearities such as : ***blocking the reception of the target signal*** and ***cross modulation***, and the additive perturbations such as internal and external noise***, inter-channel perturbations*** or ***new spectral components,*** that end up in the band of the target signal and are ***caused by intermodulatins*** between strong signals or perturbations within the preselector's band.

The influence of all these perturbations affects tge signal/perturbation ratio th the receiver output and, implicitly, the receiving quality of the useful signal. The adaptation of the receiver to the electromagnetic behavior can be realized by the automatic control of the receiver sensibility. This operation implies the using of a variable attenuator at the input of the analogic interface, with a transfer coefficient $x \leq 1$, that modifies the threshold E_0 according to [4]:

$$E_0 = E_{0in} / x \tag{1}$$

where E_{0in} - initial disturbing threshold of the analogic interface for $x = 1$.

2. **FUNCTIONAL RELATION BETWEEN THE OUTPUT RECEIVING POWER AND THE SIGNAL/PERTURBATION RATION**

The signal-to-perturbation ratio is an important parameter of a radio receiver that is carefully studied during the design phase as well as during the system exploiting. The monitoring of the signal-to-perturbation ratio in real operating conditions, when real signals and perturbation exist at the receiver input, allows the adaptation of the receiver architecture to the real electromagnetic context, in order to maximize the signal-to-perturbation ratio [4]. In order to prove this, we start from the signal-to-perturbation ratio expression the the receiver output z:

$$z = \frac{P_s}{P_{z0} + P_{ze} + P_n} \tag{2}$$

Where : P_s – the power of useful signal at the receiver output; P_{z0} , P_{ze} – the power of the internal an external noises, respectively, transferred at the receiver output; P_n – the power of new spectral components power , transferred at the receiver output, created by the non-linear transformations in the receiver. In order to maximize the signal-to-perturbation ratio, without the separation of the components of the output signal (useful signal, internal and external noises, distortions), we analyze the summing process *y*, at the receiver output :

$$y = P_s + P_{z0} + P_{ze} + P_n \tag{3}$$

Taking into account the notations in fig. ,where: x – represents the power transfer coefficient of the input variable attenuator, K – the power gain in the receiver path (on the one hand the analog and on the other hand the digital signal processing), results:

$$P_s = P_{sA} \cdot x \cdot K;\ P_{z0} = P_{z0\,\mathrm{int}} \cdot K;\ P_{ze} = P_{zeA} \cdot x \cdot K \tag{4}$$

where: P_{sA}, P_s – the useful power signal at the antenna terminal and the receiver output, respectively; P_{zeA} , P_{ze} – the external noise power at the antenna terminal and receiver output, respectively; $P_{z0\,\mathrm{int}}$, P_{z0} – the internal noise power at the input and at the receiver output, respectively; P_{grA}, P_{gr} – the power perturbations grouped in the crossing band of the preselector at the antenna terminal and, respectively, into preselector receiver, where the non-linear distortions affect the useful signal.

The power components resulting from linear transformations taking place in the analog interface - P_n , depends, on one hand, on some properties of nonlinear analog interface, highlighted by the transfer function, which can be approximated by a polynomial of order *n* and, on the other hand, the power perturbations in the crossing band of the preselector P_{grA} and the attenuation coefficient *x* :

$$P_n = \sum_{i=1}^{n} a_i P_{gr}^i = \sum_{i=1}^{n} a_i P_{grA}^i \cdot x^i = \varphi(x) \tag{5}$$

The relation (5) $\varphi(x)$ highlights the dependence of P_n by *x*, representing a polynominal with the same order as the nonliner transfer function analog interface. The summing process *y* and its components of the value *x* are shown in fig. 2.

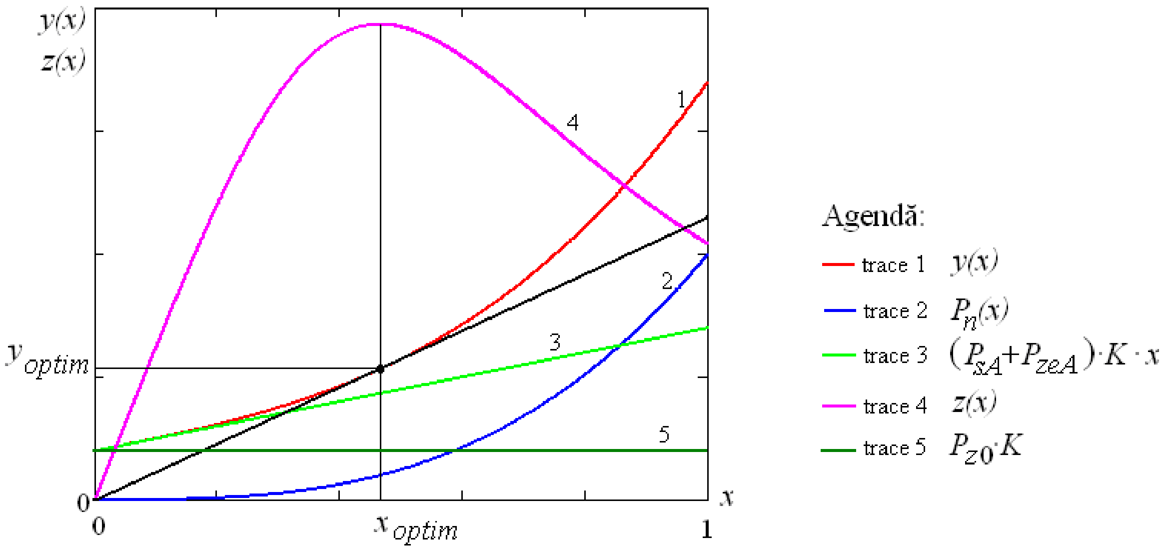

Fig. 2 Dependence of the summing process *y*, its components and the signal/perturbations of the value of *x*

The analysis of this figure show that, at small values of the attenuator transfer coefficient, the most important disturbances are due to the receiver internal noise, and, at high levels, it begins to rise up the influence of the nonlinear effects which appear in the analogic interface and not only. In these circumstances, the functional dependence between the signal/interference and the power summing process, both dependent of the attenuator transfer coefficient value input x, will be :

$$z(x)=\frac{P_{sA}\cdot K\cdot x}{P_{z0}+P_{ze}\cdot\varphi(x)}=\frac{P_{sA}\cdot K\cdot x}{y(x)-P_{sA}\cdot K\cdot x}=\frac{P_{s1}\cdot x}{y(x)-P_{s1}\cdot x} \tag{6}$$

where we denote $P_{s1}=P_{sA}\cdot K$ as the power of the receiver output signal due to the absence of input attenuator. To obtain a maximal signal/perturbations ratio, the first order derivate of z with respect of x must be zero, which means:

$$\frac{\partial z}{\partial x}=\frac{P_{s1}\cdot\left[y(x)-x\frac{\partial y}{\partial x}\right]}{\left[y(x)-P_{s1}\cdot x\right]^2}=0 \tag{7}$$

From the relation above results that, in case of:

$$y(x)=P_{s1}\cdot x+P_{z0}+P_{ze}\cdot\varphi(x)\neq 0 \text{ şi } P_{s1}\neq 0, \tag{8}$$

which is always true in practice, the optimal value of the attenuator transfer coefficient $x=x_{optim}$, for which the signal/perturbations ratio becomes maximal, corresponds to the condition:

$$\frac{\partial y}{\partial x}=\frac{y}{x} \tag{9}$$

As indicated in the fig. 2, from geometric point of view, this equation relates to the tangential line that the characteristic $y(x)$, that crosses the origin and the coordinates.

During the exploitation, the modification of the electromagnetic context, due to the frequency changing or other parameters (e.g. the automatic amplification gain according to the useful signal level), will change the dependence $\varphi(x)$ as well as the transfer coefficient of the receiver, K. Consequently, the optimal value of the transfer coefficient of the attenuator, $x=x_{optim}$ (that lead to the maximal signal/perturbations ratio), will be alos changing. Therefore, the condition (9) becomes general, independent of the causes that produce the signal/perturbations ration changing.

3. INITIALIZATION OF THE TRANSFER COEFFICIENT OF THE ATTENUATOR

For a fast convergence of the automatic system adaptation to the electromagnetic context, the first problem that must be solved is the initial value of the transfer coefficient of the attenuator, x_0. This operation should be done when the system is switched on or when an essential modification of initial conditions happens (e.g., the change of operating frequency). In such conditions, the receiver must be protected against the strong perturbations. For this purpose, we propose a statistical method based on the control of the dispersions of the perturbations located in the preselector bandpass.

Knowing the operation frequency of the receiver as well as its performances, we can establish precisely the receiver bandwidth B, that is much larger than the spectral band of the useful signal, B_i. Therefore, if the number of disturbing stations in the band pass of the preselector, $N=B/B_i$ is sufficiently large, the distribution law of the grouped perurbations $\xi=\sum_{i=1}^{N}\xi_i$, converge to a normal distribution (according to the central-limit theorem). Let assume that a statistical analysis of the electromagnetic context is available, which is possible for the cognitive radio system. In this case, we know the individual values of the dispersion of each random process, $\xi_i(t)$ and, considering that the processes are independent, the summing process can be computed as

$$\sigma^2=\sum_{i=1}^{N}\sigma_i^2. \tag{10}$$

If such statistical analysis is not available and considering that the random process $\xi(t)$ is ergodic, its dispersion is computed as :

$$\sigma^2 = \frac{1}{T}\int_0^T \xi^2(t)\,dt. \qquad (11)$$

The receiver protection condition implies that the level of the random process $\xi(t)$does not exceed the distributing threshold E_0 (expression (1)). Consequently, the probability of the useful signal reception, considering that the signals have a strong level at the input of the receiver, is :

$$P_r = P\left(|\xi| \le E_0\right) = 2F\left(E_0/\sigma\right) - 1, \qquad (12)$$

Where :

$$F\left(E_0/\sigma\right) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{E_0/\sigma} \exp\left(-\frac{v^2}{2}\right) dv. \qquad (13)$$

Imposing a given receiving probability of the useful signal P_r , we can asses the disturbing level of the preselector for a given bandpass, according to the initial data. For example [4], for $P_r = 0{,}67$, $E_0 = \sigma$; for $P_r = 0{,}99$, $E_0 = 2{,}3\sigma$, and for $P_r = 0{,}999$, $E_0 = 3\sigma$.

Knowing the disturbing level of the analogic interface, E_{0in} , from (1), we can devise the initial value of the transfer coefficient of the attenuator at the receiver input :

$$x_0 = \frac{E_{0in}}{\sigma F^{-1}\left(\frac{P_r + 1}{2}\right)}. \qquad (14)$$

Using the statistical method for initialization of the transfer coefficient of the attenuator at the receiver input reduces the redundancy of the automatic sensitivity control. Indeed, two situations are possible

- either a part of the receiving channels will be irreversibily disturbed, because of the fact that the numerical characteristics concerning the grouped perturbations are statistically predicted;
- either the protection ensured by the initial value *x* is redundant, especially when the receiver perturbations happen in the non-linear additive channels. In this case, the intermodulation components will entry in the usefull band

For these reasons, after establishing the initial conditions, the adaptation to the electromagnetic context is required, using the signal/perturbation ratio maximization criterion.

4. IMPLEMENTATION SOLUTION

For implementation purpose, let us start from a following example : we suppose a receiver in SR technology with a sensibility $E_{s\min}$ higher than $1\,\mu\text{V}$, with a dynamic range of input signal and perturbations D_{int} of 100 dB.

For simplification reason, we consider a analog digital converter (DAC) on *b*=16 biţi, with a maximum amplitude of 2 V peak-to-peak. Then, the quantification step of this converter is [3]:

$$Q = \frac{Y_{\max}}{2^{b-1}} = \frac{2\,\text{V}}{2^{16-1}} = 61\,\mu\text{V}, \qquad (18)$$

and its range is :

$$D_{DAC} = 6{,}02 \cdot b\,\text{dB} = 6{,}02 \cdot 16\,\text{dB} = 96{,}32\,\text{dB}. \qquad (16)$$

The amplitude gain of the analogic interface should be larger than :

$$G = 20\lg\frac{Q}{E_{s\min}} = 20\lg\frac{61\,\mu\text{V}}{2\sqrt{2}\,\mu\text{V}} \approx 26. \qquad (17)$$

For the adaptation to the electromagnetic context, the automatic control of the sensitivity should have a control parameter larger than :

$$[illegible]. \qquad (18)$$

These results lead to a possible implementation using the variable gain amplifier LMH6517, that contains a low noise amplifier with a gain of 22 dB and the automatic gain control of range 31,5 dB and a step of 0,5 dB. This device is well adapted with the DAC ADC16DV160. The diagram of such system is presented in the figure 3.

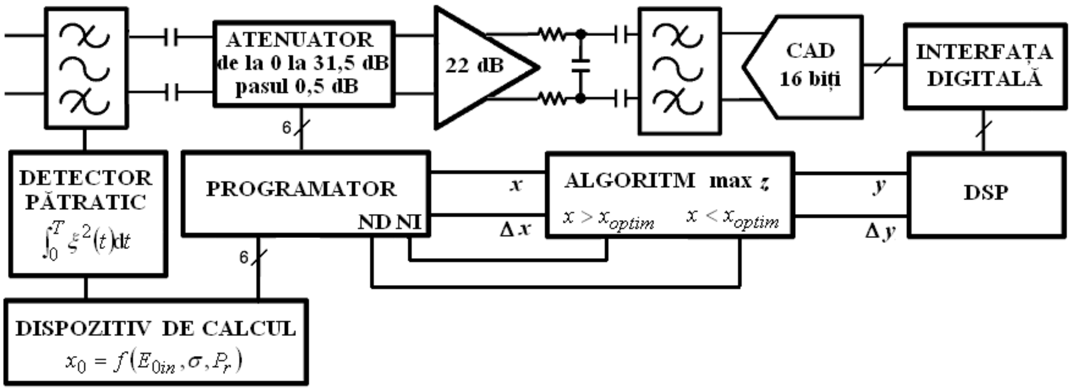

Fig. 3 Implementation diagram

In order to get the optimal value of the transfer coefficient of the attenuator, as indicated by (9), the following parameters must be studied $x, y, \partial x/\partial y$. If :

$$\frac{\partial y}{\partial x} > \frac{y}{x}, \text{ then } x > x_{optim}, \qquad (19)$$

And if :

$$\frac{\partial y}{\partial x} < \frac{y}{x}, \text{ then } x < x_{optim}. \qquad (20)$$

The objective function, for a receiver with adaptive adaptation at the electromagnetic context based on the sensitivity control according to the maximization of the signal/perturbations ratio, can be defined as :

$$S(x) = \frac{\partial y}{\partial x} - \frac{y}{x} \cong C, \qquad (21)$$

Or :

$$|S(x)| < \varepsilon \qquad (22)$$

where: ε is the admitted error in (21).

From this expression, it follows that automatic adaptive system at the electromagnetic context, based on the sensitivity setup according to the signal/perturbations ratio, must allow a periodic modification of the value of attenuator coefficient. Nevertheless, this modification should remain small with respect of the initial value, so that the variations of the output, $\Delta y \approx \mathrm{d}y$, remain comparable with the total power of the noise. In the case presented in the figure 3, we consider Δx of 0,5 dB. In order to ensure a periodic modification of the attenuator coefficient, a programmable device is used, for both initial values setup and the increasing/decreasing of the attenuator coefficient with a step 0,5 dB. The control system is done according to the algorithm presented in the figure 4.

5. CONCLUDING REMARKS

For the work presented in this paper, the following aspects can be concluded :

1. The maximization of signal/perturbations ratio at the receiver output, in operational conditions, can be achieved by analyzing the functional dependence of the summing process power (at the receiver output) on the input attenuation coefficient, without separating its component;

2. The adaptation algorithm can be easily implemented in the receiver structure if this one contains an appropriate computing system.

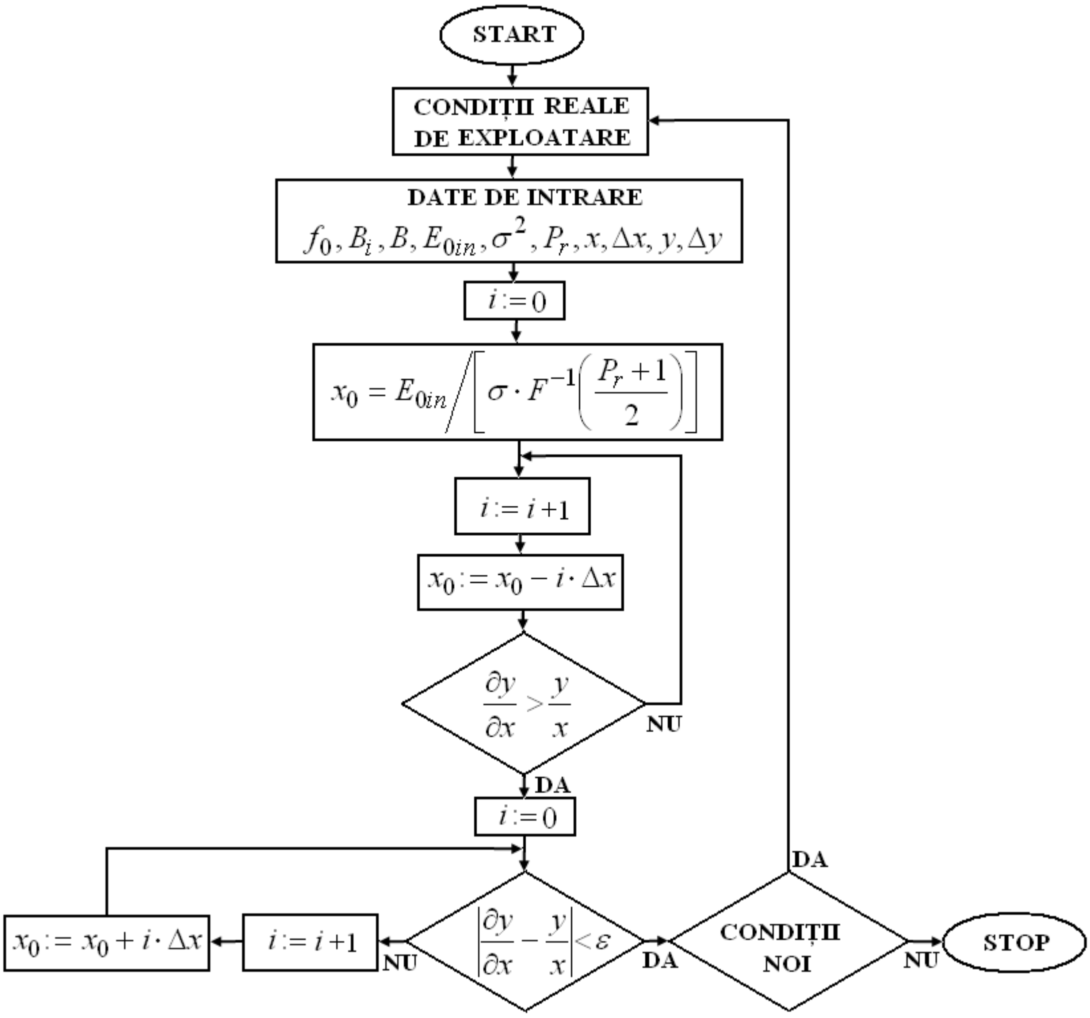

Fig. 4 The adaptation algorithm at the electromagnetic context

3. The adaptation algorithm takes into consideration the fact that the initial design, based on the statistic criteria, is redundant. Therefore, the value of the attenuator coefficients is decreased until the nonlinear effects in the receiver are perceptible (until the condition (19) is satisfied). From this moment, the objective function (22) is checked. If the condition is “YES”, the system remains in stand-by until a significant modification of the initial conditions happens. If “NO”, the value of attenuator transfer coefficient is incremented until the objective function is achieved.
4. The proposed method reduces the redundancy of the protection system while the only the perturbations coming from additional channels are taken into account.

6. REFERENCES

[1] Mitola, J., *Software Radio Architecture*: *Object-Oriented Approaches to Wireless Systems Engineering*. John Wiley & Sons, Ltd., 2000.
[2] Tuttlebee W. (Ed.), *Software Defined Radio: Enabling Technologies*, John Wiley & Sons, Ltd., 2002.
[3] Bălan, C., *Receptoare radio cu prelucrare digitală a semnalelor*, Academia Tehnică Militară, Bucureşti, 2003.
[4] Bălan, C., *Receptoare radio profesionale - traseul analogic*, Academia Tehnică Militară, Bucureşti, 1997.