PARAMETER DISTRIBUTION IN RECEIVER CHAINS: A HYBRID FUZZY-GENETIC ALGORITHM APPROACH

Laura-Nicoleta IVANCIU, Gabriel OLTEAN
Technical University of Cluj-Napoca, Romania, 28, Memorandumului street, Cluj-Napoca
Laura.Ivanciu@bel.utcluj.ro

Abstract: The paper presents a novel, hybrid approach to parameter distribution in receiver chains, using fuzzy sets and Genetic Algorithms. The method works with global values for gain, noise figure and intercept points, and aims to correctly assign distributed values of these metrics for each block of the receiver chain. Z-shaped and S-shaped membership functions are used for each of the 4 metrics. The objective function of the Genetic Algorithm is defined as a sum of membership degrees. Tests using a zero-IF receiver architecture with 5 blocks, and WCDMA/WLAN specifications, show that the proposed method rapidly assigns correct values for gain, noise figure and intercept points, for each block.

Keywords: *parameter distribution, receiver, WCDMA, WLAN, fuzzy, genetic algorithm*

I. INTRODUCTION

A complete telecommunications system consists of two signal paths: the transmission path and the reception path. The two paths are complementary, meaning that if a transmitter contains a modulator and a high frequency converter, the receiver needs to have a low frequency converter and a demodulator.

This paper focuses on the receiver path, namely the blocks that works with analog signals, also known as "front-end" (FE) or "analog front-end".

A radiofrequency (RF) receiver has to fulfill the main functions listed below [1]:

- down-conversion (conversion to low frequencies)
- amplification of the signal, up to suitable level for the ADC (analog-to-digital converter)
- rejection of all interference signals, thus preventing them to appear at the input of the ADC

RF receivers consist of one or more blocks of the following types: filter, LNA (low noise amplifier), mixer, VGA/PGA (variable/programmable gain amplifier).

For receivers that have the ADC positioned in low frequency domain, there are four basic types of architectures: superheterodyne, zero IF or direct conversion, low IF, and double conversion. This paper addresses the zero IF architecture, depicted in Figure 1 [2].

For any given receiver architecture, there are certain global metrics used in performance evaluation, such as: gain, noise figure (NF), nonlinearity parameters (second and third order intercept points – IIP2 and IIP3). When dealing with cascaded blocks, the overall values for the previously mentioned parameters are computed using the formulas in equations (1) – (3) [2].

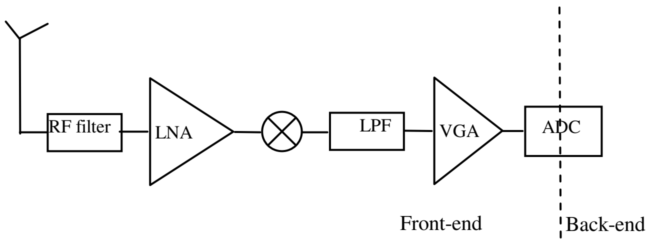

Figure 1. Zero-IF architecture – simplified model[2]

$$G\,[dB] = \sum_{i=1}^{n} G_i \tag{1}$$

$$nf = 1 + (nf_1 - 1) + \frac{nf_2 - 1}{G_1} + ... + + \frac{nf_n - 1}{G_1 ... G_n} \tag{2}$$

$$\frac{1}{IIP_k} = \frac{1}{IIP_{k,1}} + \frac{G_1}{IIP_{k,2}} + \frac{G_1 G_2}{IIP_{k,3}} + ... + \frac{G_1 ... G_{n-1}}{IIP_{k,n}} \tag{3}$$

where nf – total noise figure, G – total gain, IIP_k – total k order intercept point; nf_i , G_i, $IIP_{k,i}$ – noise figure gain, and k order intercept point of block i, $i = 1…n$, $k = 2, 3$.

A typical problem that designers struggle with is parameter distribution along the receiver chain: provided that the global values of gain, noise figure and IIP2/IIP3 are specified, how does one assign values of each of these metrics to each block in the receiver path, so that the global values fulfill the specified conditions? The problem description can be translated in terms of minimization,

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which makes the use of Genetic Algorithms (GAs) a suitable approach.

Tools that compute the global parameters for cascaded blocks are available online, for free [4-5]. On the other hand, systems that distribute parameters are less likely to be found, since the matter takes into account a large number of interconnected variables. A frequency planning and comparison tool for multi-standard receivers, based on intelligent agents is implemented in [6]. Gain, noise figure and IIP3 budgeting for an LTE receiver front-end is performed in [7], using a systematic approach and specifications for receiver sensitivity and band. Physical layer parameters are involved in the complete design of a transceiver RF front-end for 2.45 GHz RFID readers [8].

Although the proposed method does not take into account parameters such as the dynamic range or effective number of bits of the ADC, it represents a solid starting point in the complete design of a receiver front-end.

Genetic Algorithms (GAs), as a class of Evolutionary Algorithms, are techniques that use biology inspired operations, such as selection, mutation, crossover and inheritance. Heuristic search is used to find the solution vector x that minimizes the so-called objective function, $f(x)$. GAs work with a population of individuals, called chromosomes. Each individual consists of genes, or variables.

The vector x is subject to the following constraints [9]:

$$\begin{aligned} & g_j(x) < 0, j = \overline{1,...,M} \\ & h_k(x) = 0, k = \overline{1,...,K} \\ & a(l) \le x(l) \le b(l), 1 \le l \le n \end{aligned} \tag{4}$$

The terms $g_j(x)$ and $h_k(x)$ are called inequality and equality constraint functions, where M and K are the number of inequality and equality constraints. Besides, each $x(l)$ represents a gene (a variable) whose boundaries are defined by $a(l)$ and $b(l)$ [9].

The paper is organized as follows: Section II presents how the system was developed; Section III highlights the correct and rapid functioning of the system, when tested for a typical receiver architecture; Section IV draws some conclusions and indicates possible future developments.

II. DEVELOPMENT OF THE SYSTEM

The block diagram of the parameter distribution system (PDS) is presented in Figure 2. The system was developed in Matlab, making good use of the predefined functions for fuzzy sets and GAs.

The inputs are the global values for gain (dB), noise figure (dB), IIP3 (dBm), IIP2 (dBm). The system is currently designed for five blocks, but can easily be extended to accept any number of blocks. PDS returns the distributed values of the parameters across the blocks. As each block is defined by four parameters, the output array will be *4 * no. of blocks* long.

In order to associate proper values for gain, noise figure, IIP3 and IIP2 for each block, the system uses the workflow in Figure 3.

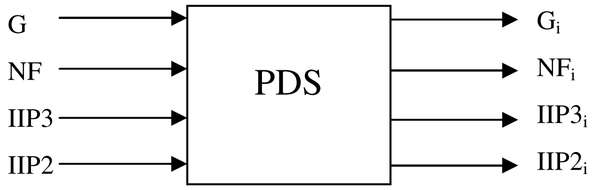

Figure 2. Block diagram of PDS

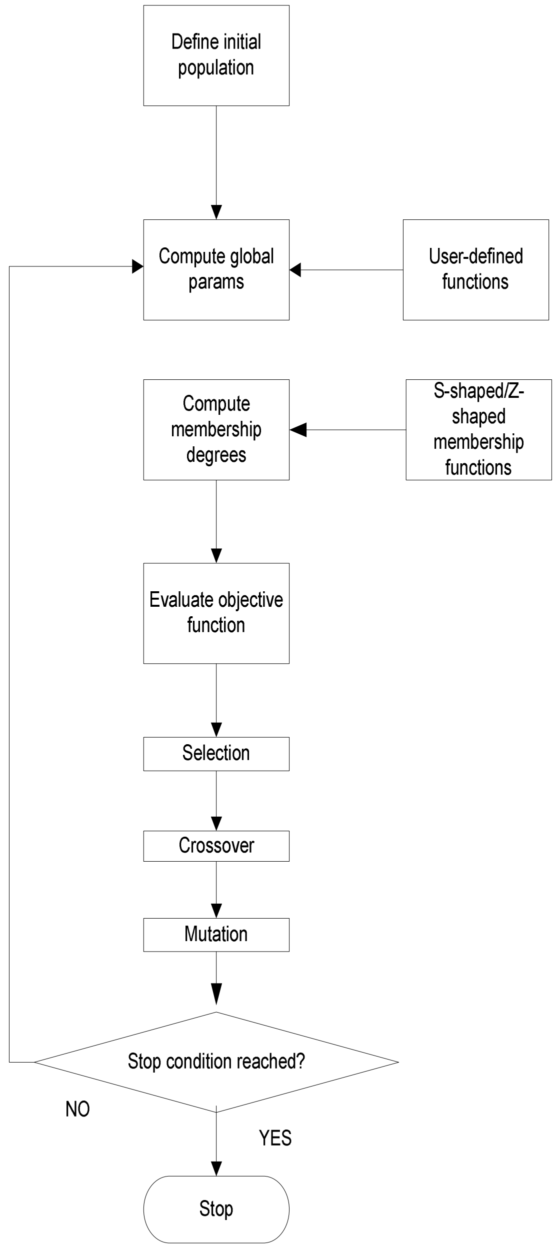

Figure 3. PDS workflow

Since the global values of the parameters are defined as *larger than (>)* or *smaller than (<)*, the handiest way to translate these conditions into fitness function material for the GA was to use fuzzy sets. Take gain for instance: standards specify that it should be above 70 dB, for example. So every value higher than 70 dB is suitable, which leads us to using a Z-shaped membership function. Everything less than 70 dB has a membership degree higher than 0, whereas all values over 70 dB have a 0 membership degree, which is what we are looking for.

For parameters that are described as *smaller than*, S-shaped membership functions are used; each point below the target value has a null membership degree.

Computing the global values of the parameters is achieved using several user-defined Matlab functions, based on equations (1) – (3). It is worth mentioning that all the computations use linear domain values, so the conversion from dB/dBm to linear scale and vice versa was performed in each of the functions.

The GA tries to minimize the objective function described as follows:

$$f(x) = \mu_{Gain}(x) + \mu_{NF}(x) + \mu_{IIP3}(x) + \mu_{IIP2}(x) \quad (5)$$

where $\mu_{Param}(x)$ is the membership degree of point x to the fuzzy set *Param.*

Each individual of the population consists of 20 variables:

$$[\, G_{\overline{1..5}} NF_{\overline{1..5}} IIP3_{\overline{1..5}} IIP2_{\overline{1..5}} \,] \quad (6)$$

The first 5 genes are the gains for each block; the next 5 are the noise figures, followed by 5 values for IIP3 and 5 values for IIP2.

Several linear inequality constraints are defined, considering that the five blocks in the receiver front-end are, in order: RF filter, LNA, mixer, BB filter and VGA. These constraints should be changed accordingly when using the blocks in a different order.

The fitness value associated to each individual is the result of the objective function, which should be as close to 0 as possible. The lower the value of the objective function, the fitter the individual is, thus increasing its chances of survival in the next generation.

III. EXPERIMENTAL RESULTS

The system was tested using the specifications of two well-known communications standards, WCDMA (Wideband Code Division Multiple Access) and WLAN (Wireless Local Area Network) (Table 1) [10]. Because the system is developed and validated entirely in Matlab, the results may slightly change, when integrating the dependencies between

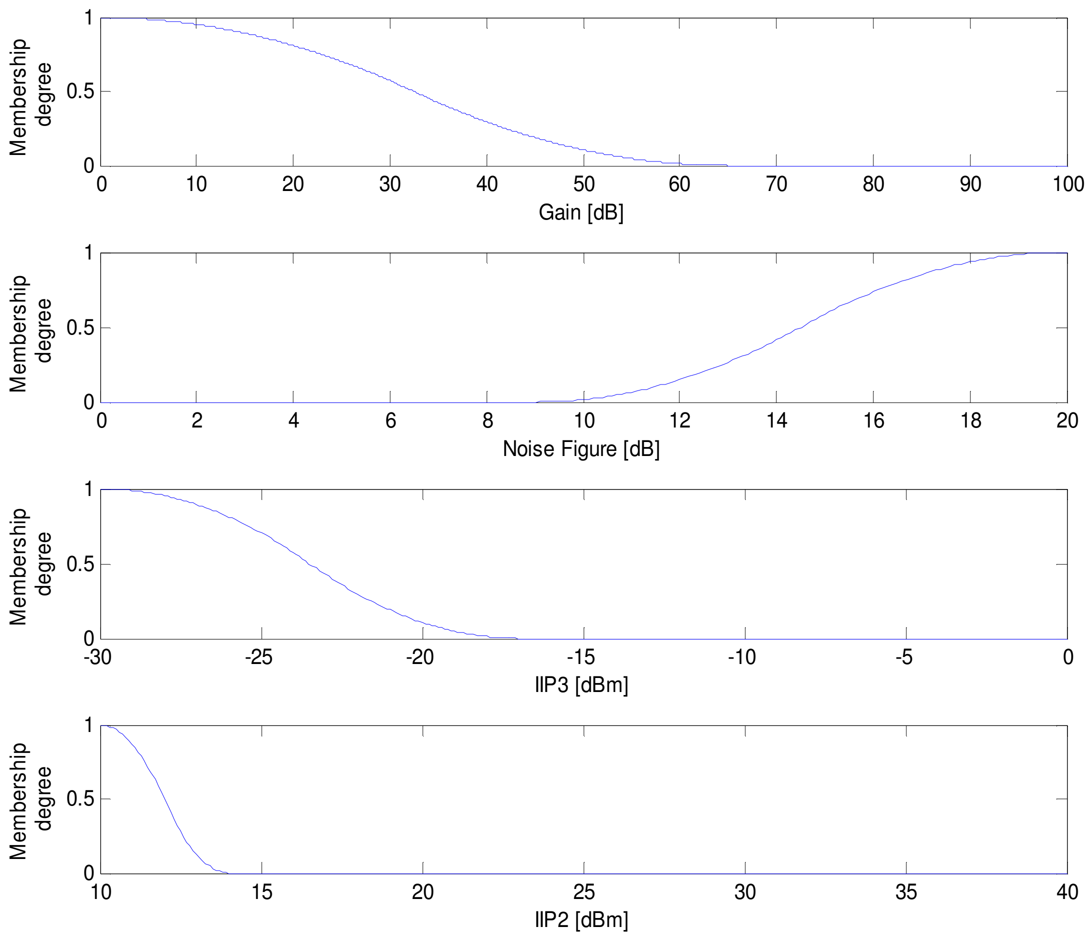

Figure 4. Membership functions - WCDMA

variables that may occur at the physical layer.

Given the fact that the standards do not specify a minimum value for the global gain, 60 dB was considered a proper minimum value, in both cases.

Figure 4 depicts the membership functions defined for the global gain, noise figure, IIP3, and IIP2, for WCDMA. As explained in Section II, Z-shaped membership functions were used for gain, IIP3 and IIP2, whereas for noise figure, given as *smaller than*, an S-shaped was defined. The universe of discourse and parameters for each membership function are listed in Table 2.

For starters, a population of 100 individuals was used. The algorithm is set to stop if it reaches 150 runs or the value of the objective function does not change significantly for several consecutive runs. The evolution of the best and mean values of the objective function and a bar chart of the current best individual for WCDMA is depicted in Figure 5 for WCDMA and Figure 6 for WLAN. Several runs showed that 150 runs for WCDMA, respectively 250 runs for WLAN are enough for the GA to converge.

Table 1. Design specifications [10]

Standard / Parameter	WCDMA	WLAN
Gain [dB]	-	-
NF [dB]	< 9	< 11
IIP3 [dBm]	> -17	> -5
IIP2 [dBm]	> 14	> 23

The final values for the distributed parameters are listed in Table 3. Based on the bar charts in Figures 5 and 6 and on Table 3, it can be observed that the gain of the fifth block, the VGA, is the highest, while the gain of the mixer is the lowest and very close to the gain of the RF filter, in both cases. The values of IIP2 are very high, for each of the five blocks.

Table 2. Definition of membership functions - WCDMA

Name	Type	Univ. of discourse	Params
Gain	Z-shaped	[0…100]	[0 60]
NF	S-shaped	[0…20]	[9 20]
IIP3	Z-shaped	[-30…0]	[-30 -17]
IIP2	Z-shaped	[10…40]	[10 14]

Table 3. Final values of the distributed parameters

	WCDMA				
Param	**RF filter**	**LNA**	**Mixer**	**LPF**	**VGA**
Gain	4.57	5.15	4.49	12.18	38.50
NF	5.34	10.49	7.42	6.38	11.14
IIP3	9.76	7.14	8.02	8.62	9.96
IIP2	35.93	48.41	38.15	47.85	45.92
	WLAN				
Param	**RF filter**	**LNA**	**Mixer**	**LPF**	**VGA**
Gain	2.54	4.17	1.31	12.36	44.68
NF	9.06	5.97	7.65	9.32	13.74
IIP3	15.66	15.69	15.56	15.75	15.98

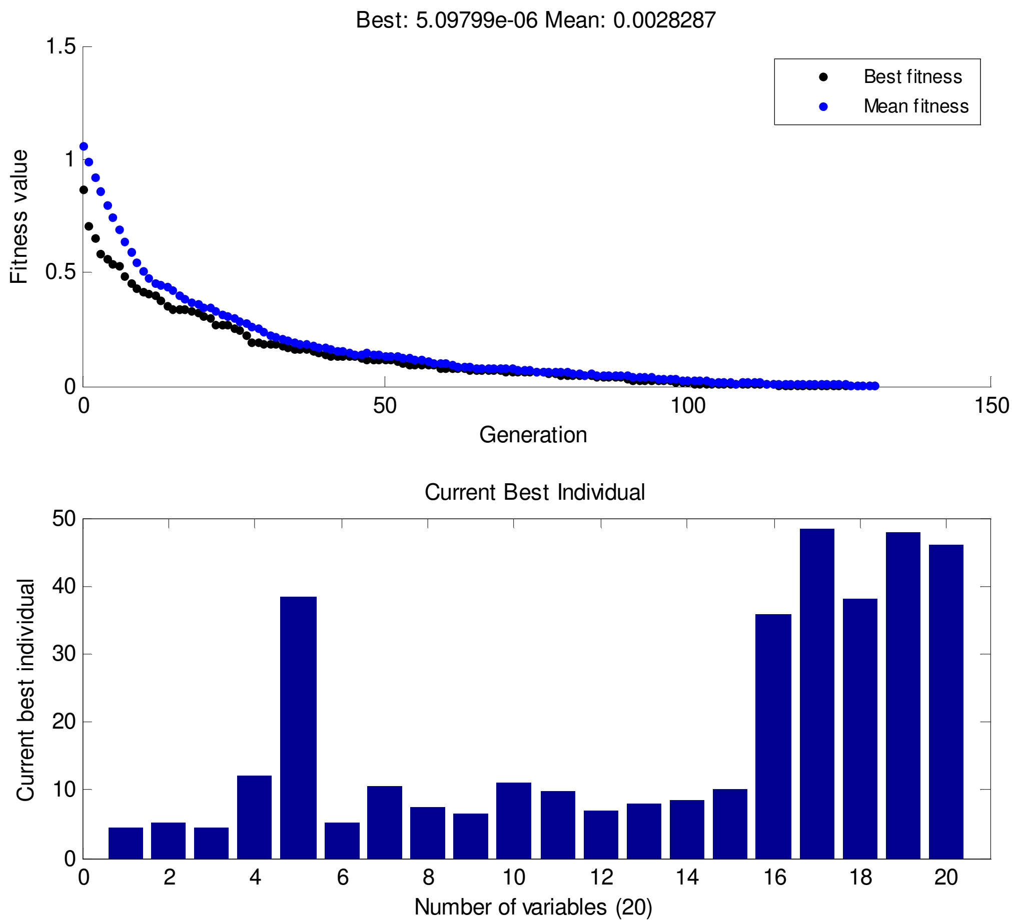

Figure 5. Best/mean fitness function evolution; current best - WCDMA

IIP2	41.14	41.38	41.33	38.67	50.15

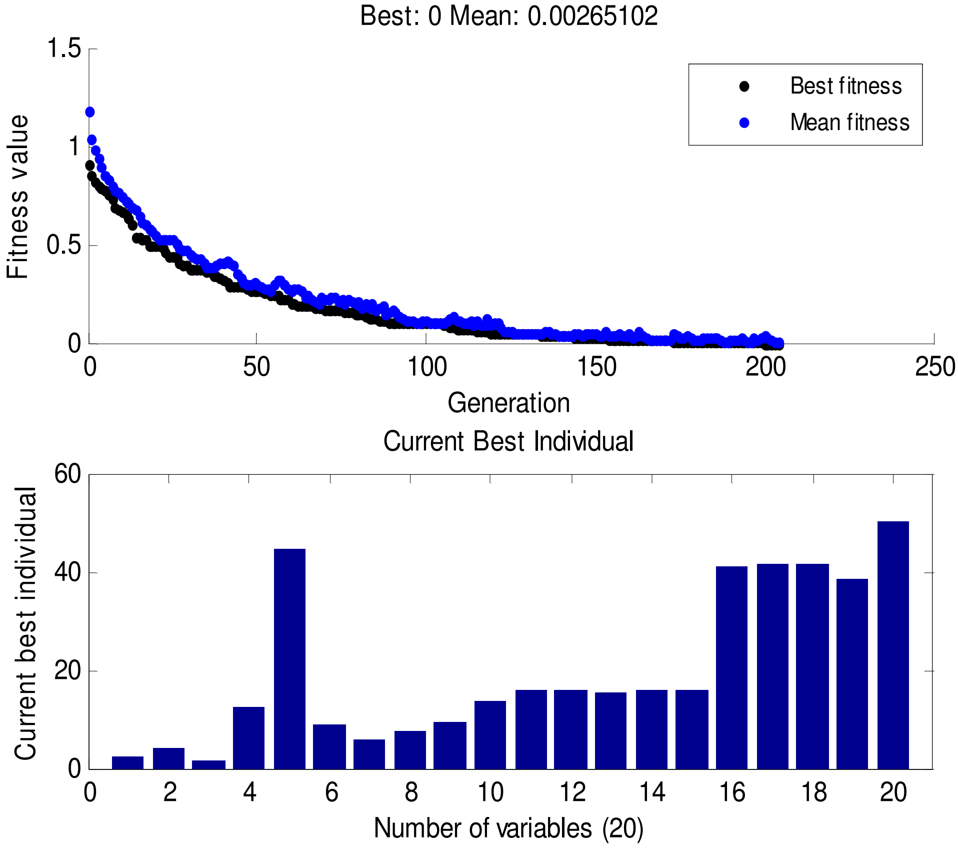

Figure 6. Best/mean fitness function evolution; current best - WLAN

Table 4 compares the global values to the specified ones, pointing out that the system provides very good results, in both cases. Also, it is worth mentioning that the entire process lasts only a few seconds.

Table 4. Design specifications and results

Standard / Parameter	WCDMA		WLAN	
	Specs	**Result**	**Specs**	**Result**
Gain [dB]	-	64.9	-	64.4
NF [dB]	< 9	8.81	< 11	10.9
IIP3 [dBm]	> -17	-16	> -5	-4.8
IIP2 [dBm]	> 14	18.75	> 23	25.5

IV. CONCLUSIONS AND FUTURE WORK

The system proposed in this paper uses a hybrid fuzzy-genetic algorithm approach to parameter distribution in receiver chains. The fact that the typical global parameters of a receiver chain (gain, noise figure, intercept points) are stated as *smaller than* or *larger than*, leads us to use fuzzy sets in defining these parameters. Genetic Algorithms come as a natural solution to minimizing an objective function, given as a sum of membership degrees. The presented solution achieves a very fast parameter distribution of the global metrics mentioned before.

Although the system is currently designed to work with 5 blocks, it can easily be adjusted to accept a user-given number of blocks.

Experimental runs using global parameter values for WCDMA and WLAN proved that PDS is able to solve the optimization problem in a very short time.

The system can be used a strong starting point in the process of completely designing a receiver chain. Future developments can address the flexibility of the system (e.g. introducing user-defined constraints) or its use in correlation with some other tool, that shows whether the values of the distributed parameters are achievable in real implementations (e.g. connecting the system to a circuit simulator).

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REFERENCES

[1] S. A. R. Duenas, *"Multi-Band Multi-Standard CMOS Receiver Front-Ends for 4G Mobile Applications – Ph.D. thesis"*, KTH Royal Institute of Technology, Stockholm, Sweden, 2009.
[2] B. Razavi, *RF Microelectronics*, Prentice Hall PTR, 1998.
[3] L. Zhang, *"System and Circuit Design Techniques for WLAN-Enabled Multi-Standard Receiver – Ph.D. thesis"*, Ohio State University, USA, 2005.
[4] Advance design system eda software. [Online]. Available:

http://www.eesof.tm.agilent.com/ [Accessed: October 28, 2013].
[5] Cascade. [Online]. Available: http://www.nathanyer.com/ [Accessed: October 28, 2013].
[6] D. Rodriguez de Llera Gonzales, A. Rusu, M. Ismail, H. Tenhune, "TACT - a multi-standard RF transceiver architecture comparison tool", *Circuits and Systems, 2005. 48th Midwest Symposium on*, 7-10 Aug. 2005, pp. 659 – 662, Vol. 1, ISBN: 0-7803-9197-7.
[7] M.M. Vinay, R. Paily, A. Mahanta, "Gain, NF and IIP3 Budgeting of LTE Receiver Front End", *VLSI Design and 2013 12th International Conference on Embedded Systems (VLSID), 2013 26th International Conference on*, 5-10 Jan. 2013, Pune, pp. 191-196, ISBN: 978-1-4673-4639-9.
[8] N.A. Ibrahim, H.M. Ahmed, A.M. El-Tager*, "Design of a transceiver RF front-end for 2.45 GHz RFID readers",* Antennas and Propagation (MECAP), 2012 Middle East Conference on, *29-31 Dec. 2012, Cairo, Egypt, pp. 1-5, ISBN: 978-1-4799-1277-3.*
[9] C.R. Reeves, J.E. Rowe *Genetic Algorithms: Principles and Perspectives,* Kluwer, Norwell, MA, 2001.
[10] 3GPP Specifications. [Online]. Available: http://www.3gpp.org/ [Accessed: October 28, 2013].