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Araştırma Makalesi Research Article

GRİ KURT ALGORİTMASI İLE 900 MHZ GSM BANT UYGULAMALARI İÇİN DÜŞÜK GÜRÜLTÜLÜ KUVVETLENDİRİCİ TASARIM OPTİMİZASYONU

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Anahtar Kelimeler

Düşük Gürültülü Yükselteç, GSM, Kablosuz Haberleşme, Gri Kurt, Optimizasyon.

Öz

Bu çalışmada GSM uygulamalarına yönelik, yüksek performanslı bir düşük gürültülü kuvvetlendirici (DGK) tasarımı ele alınmıştır. Toplam sistemin gürültüsüne olan baskın etkisinden dolayı, DGK kablosuz haberleşme sistemlerinin anahtar elemanlarından biridir. Her ne kadar da birden çok transistor elemanı ve kat yapısı kullanılarak çok yüksek kazanç ve düşük gürültü karakteristiği elde edile biliniyor ise de, bu yöntem toplam tasarım karmaşıklığını ve üretim maliyetini ciddi bir şekilde etkilemektedir. Bu çalışma kapsamında, tek bir transistor elemanı kullanılarak 14.3 dB kazanç, 15 dB den düşük geri donuş kaybı ve 1.8 dB seviyesinde gürültü karakteristiği gösteren GSM 820-980 MHz uygulamalarına uygun bir tasarım önermektir.

DESIGN OPTIMIZATION OF LOW NOISE AMPLIFIER FOR 900MHZ GSM BAND APPLICATIONS USING GREY WOLF ALGORITHM

Keywords

Low Noise Amplifier, GSM, Wireless Communications, Grey Wolf, Optimization.

Abstract

In this work, the design of a high-performance single-stage Low Noise Amplifier (LNA) for GSM applications is taken into consideration. LNA design is one of the key stages of a wireless communication system due to its dominance over the whole system's noise figure performance. Although it is possible to achieve a very high gain and low noise figure with the usage of multi-stage transistors, such designs would also have a high complexity and manufacturing cost. The main aim of this work is to propose a single transistor LNA design for GSM application with a gain level of 14.3 dB, return loss level of less than 15 dB, and noise figure of 1.8 dB over the operation band of 820-980 MHz. the optimal design variables of the model is obtained via Grey Wolf optimization procedure.

Alıntı / Cite

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Highlights

- Design Optimization
- High Performance LNA
- Grey Wolf Optimization

Purpose and Scope

Design optimization of high performance LNA

Design/methodology/approach

In this work, the design of a high-performance LNA stage for GSM applications had been achieved using Grey Wolf optimization technique. The main goal of the design is to achieve the requested performance with a single-stage LNA design with the lowest possible noise figure, power consumption, and design size.

Findings

Application of GWO on single stage LNA design

Research limitations/implications

The availability transistors to be used for modelling of LNA.

Practical implications

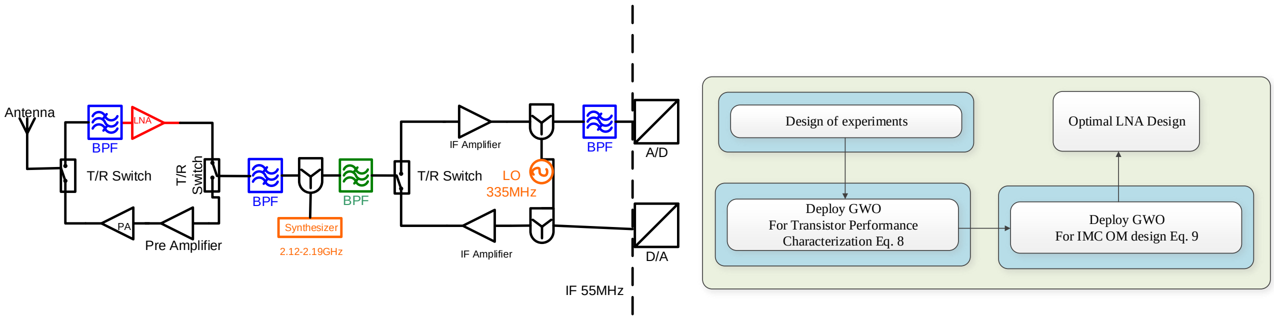
LNA design is one of the key stages of a wireless communication system due to its dominance over the whole system's noise figure performance. In any wireless communication where a lossless data communication is required LNA is a crucial element.

Originality

An efficient approach for design and optimization of LNA without need of expert knowledge using Artificial Intelligence algorithm (GWO).

1. Introduction

With respect to the ever-increasing demand for high-speed large data communications for wireless systems, the need for high performance designs has also increased. The challenges of such designs are not only limited to their performance measures but also other parameters such as cost, overall size, and material limitations with respect to applications are also other concerns that challenges the designer. One of the most commonly used applications of wireless communications is GSM, which has many uses for both civilian and military applications and is an important study field (Ulrich, 2000; Kluge, 2003; Akyildiz, 2002; Alaybeyoğlu, 2009.



(a) (b)

Figure 1. (a) Schematic Of RF Front-End Receiver, (b) Flow Chart Of Proposed Work.

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In Figure 1, a general schematic for a wireless front-end communication system is presented. The RF signal is taken via an antenna stage from the space, and then after the received signals are process to be converted from analogue to digital signals for communication. As it can be seen from the figure, the first stage and key element in wireless communication is antenna element, where its performance is essential and the methodologies to improve this performance are being studied by many researchers (Esame, 2006; Çalışkan, 2019; Koçer, 2020; Pozar, 1998), (Demirel, 2017; Mahouti, 2012; Belen, 2021; Kumar, 2019; Roobert, 2020; Khosravi, 2019; Chamg, 2019; Ke, 2018; Belostatski, 2022). However, even with a perfectly designed antenna stage, this is not sufficient to have a high performance communication system. Another key element in this system is the Low Noise Amplifier (LNA) stage, which mainly effects the sensitivity of the system to noise and unwanted signals from other sources. In this work, the design of a high performance LNA for GSM applications is taken into consideration.

2. RF Amplifier Design

As mentioned before, high-performance designs are of crucial importance to satisfy the high demands of the communication industry. LNA is one of the main elements in which the received signals are amplified with the lowest possible noise effects to increase the overall performance of the communication system. The main challenge is that the LNA must amplify the signal with the lowest possible noise figure due to the main effect of this stage's noise level on the overall noise figure of the whole system. Although it is possible to have such designs with multi-stage LNA designs, this method would also increase the complexity, overall cost, and total power consumption level of the whole design. Thus, the design of a high-performance, low power consumption LNA with a single-stage is a challenging problem where not only the mentioned challenges must be satisfied but also the design must have good impedance matching performance (Danacı, 2020; Hashemi, 2002). In this work, the scattering parameters, which are an essential material for high-performance LNA designs (Esame, 2006; Hove, 2004; Doddamani, 2007; Stece, 1999), had been used for the calculation of critical performance measures of LNA such as Noise Figure, overall gain, and bandwidth.

However, achieving these conflicting design measures is a challenging procedure that either requires a highly accurate and complex calculation and expert knowledge or via an optimization process guided by artificial intelligence algorithms (Mahouti, 2012). The performance of LNAs is heavily influenced by the design of their passive components, such as inductors and capacitors, and optimizing these components is crucial for achieving high gain, low noise, and broadband performance. Traditionally, optimization of LNAs has been performed using conventional optimization algorithms such as honey bee mating (Mahouti, 2012), genetic algorithms (Chen, 2013) and particle swarm optimization (Ulker, 2012). However, these algorithms have several limitations, including poor convergence and sensitivity to the initial solution.

Recently, a new optimization algorithm, the Grey Wolf Optimizer (GWO), has emerged as a promising alternative to conventional optimization algorithms. The Grey Wolf Optimizer (GWO) is a population-based optimization algorithm that is inspired by the hunting and preying behaviour of grey wolves and is based on a multi-objective optimization framework. The GWO algorithm is known for its ability to efficiently search the solution space, avoid local optima, and converge to the global optimal solution (Seyyedabbasi, 2023). The basic principle of the GWO algorithm is to mimic the behaviour of a pack of grey wolves hunting for their prey. The pack of wolves consists of three types of individuals: the alpha wolf, the beta wolf, and the delta wolf. The alpha wolf is the strongest and most experienced wolf; the beta wolf is the second strongest, and the delta wolf is the weakest. The GWO algorithm starts with a randomly generated initial population of candidate solutions. In each iteration, the algorithm updates the position of the wolves in the solution space based on their hunting behaviour. The alpha wolf is updated based on the best solution in the current population, the beta wolf is updated based on the second best solution, and the delta wolf is updated based on the worst solution. The updated positions of the wolves are then used to update the positions of the other individuals in the population. The GWO algorithm continues until a stopping criterion is met, such as a maximum number of iterations or a desired accuracy level (Singh, 2022). The final population of candidate solutions provides a set of potential solutions for the optimization problem, and the best solution among them represents the global optimal solution (Ahmed, 2022).

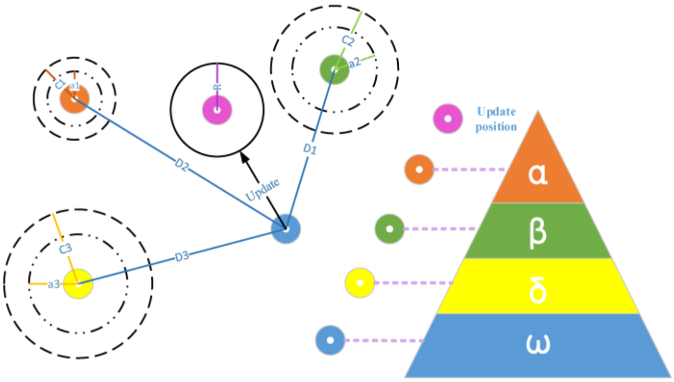

Figure 2. The Diagram Of GWO (Greywolf Optimization) Algorithm [Dai, 2018].

In this research paper, we explore the use of the GWO algorithm (Seyyedabbasi, 2023; Kiani, 2021) for optimizing the passive components of a microwave LNA. We evaluate the performance of the optimized LNA using simulation results, and compare it to LNAs optimized using other optimization algorithms. Our results show that the GWO algorithm is an effective tool for optimizing the performance of microwave LNAs and provides significant improvements in terms of gain, noise figure, and return loss using the following equations as the cost function. The obtained optimal termination value for targeted LNA design is presented in Table 1.

$$F(Z_S) = F_{min} \frac{R_n|Z_S - Z_{opt}|^2}{|Z_{opt}|^2 R_S} \tag{1}$$

$$G_T(Z_S, Z_L) = \frac{4R_S R_L |z_{21}|^2}{|(z_{11}+Z_S)(z_{22}+Z_L) - z_{12}z_{21}|^2} \tag{2}$$

$$G_{AV}(Z_S) = \frac{|z_{21}|^2}{|z_{11}+Z_S|^2} \frac{R_S}{R_{out}} \tag{3}$$

$$V_{in}(Z_S, Z_L) = \frac{1+|\rho_{in}|}{1-|\rho_{in}|}, \quad |\rho_{in}|^2 = \left|\frac{Z_{in} - Z_S^*}{Z_{in}+Z_S}\right|^2 \tag{4}$$

$$V_{out}(Z_S, Z_L) = \frac{1+|\rho_{out}|}{1-|\rho_{out}|}, \quad |\rho_{out}|^2 = \left|\frac{Z_{out} - Z_L^*}{Z_{out}+Z_L}\right|^2 \tag{5}$$

The physical realizability conditions can be given as:

$$\Re e\{Z_{in}\} = R_{in} = \Re e\left\{z_{11} - \frac{z_{12}z_{21}}{z_{22}+Z_L}\right\} > 0 \tag{6}$$

$$\Re e\{Z_{out}\} = R_{out} = \Re e\left\{z_{22} - \frac{z_{12}z_{21}}{z_{11}+Z_S}\right\} > 0 \tag{7}$$

$$\text{Cost}_1 = f(R_S, X_S, R_L, X_L) = A|F| + e^{-\frac{G_{av}}{B}} + C\left|V_{outopt}\right| + D\left|V_{inopt}\right| \tag{8}$$

Table 1. Computed Results Of GWO For BFP193W At V_{DS} =10V, I_{DS} =30ma For (F_{req}=F_{min}, V_{inopt}, V_{outopt}, G_{tmax}) Quadruplets.

f MHz	R_L	X_L	R_S	X_S	V_{in}	V_{out}	F	G_T [dB]
900	15.5	-1.6	35.9	10.7	1.7	1.7	1.6	17.5

$$\text{Cost}_2 = f(C_1, \ldots, C_5, R_1, \ldots, R_3, L_1, L_2, f) = \left|Z_{LTarget} - Z_{Li}\right| + \left|Z_{STarget} - Z_{Si}\right| \tag{9}$$

Here, Z_s and Z_L are the source and load terminations of the matching circuit which their values will be determined based on the values of design variables given in Fig. 2. All the simulations are done in advancing the Wireless Revolution Microwave Office (AWR Office) environment for the design of 900MHz for GSM applications. BFP193W (Infineon, 2023) from Infineon is taken as a high-performance transistor suitable for the selected application. The design will be placed on FR4 material with a substrate height of 1.58 mm and a die-electric constant of 4.6. In figure 2 the schematic of the aimed LNA design is presented alongside the value of RLC elements in Table 2.

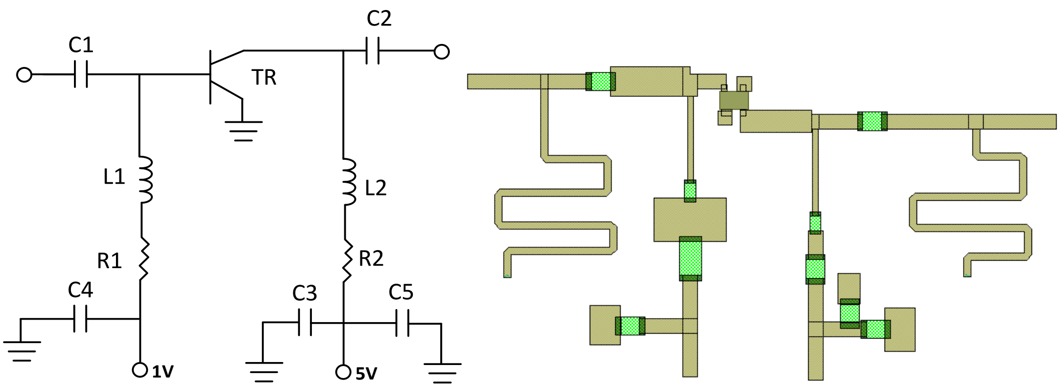

Figure 2. Schematic Views Of The LNA Designed For GSM Band Applications.

Table 2. Optimally Determined Design Variables Value Using Eq. 9

C1	100pF	**R1**	4.7Kohm
C2	100pF	**R2**	47ohm
C3	3300nF	**R3**	3.9Kohm
C4	330nF	**C5**	330nF
L1	15 nH	**L2**	10nH

In figure 3 and table 2, the simulated performance measures of the proposed LNA design is presented. As it can be seen both S_{11} and S_{22} characterises of the design is less than -15 dB while the $S_{21}$is around 14.3 dB, and the noise figures of the design is simulated as 1.8 dB for the aimed operation frequency. In Figs. 3(c) and (d) the simulated performance result of gain and 1 dB compression point of design are presented. As it can be seen form the presented results in Table 2, the proposed design achieves sufficiently good performance characteristics for GSM band applications with a low power consumption level of 300 mW and a low design area of 45x25mm2.

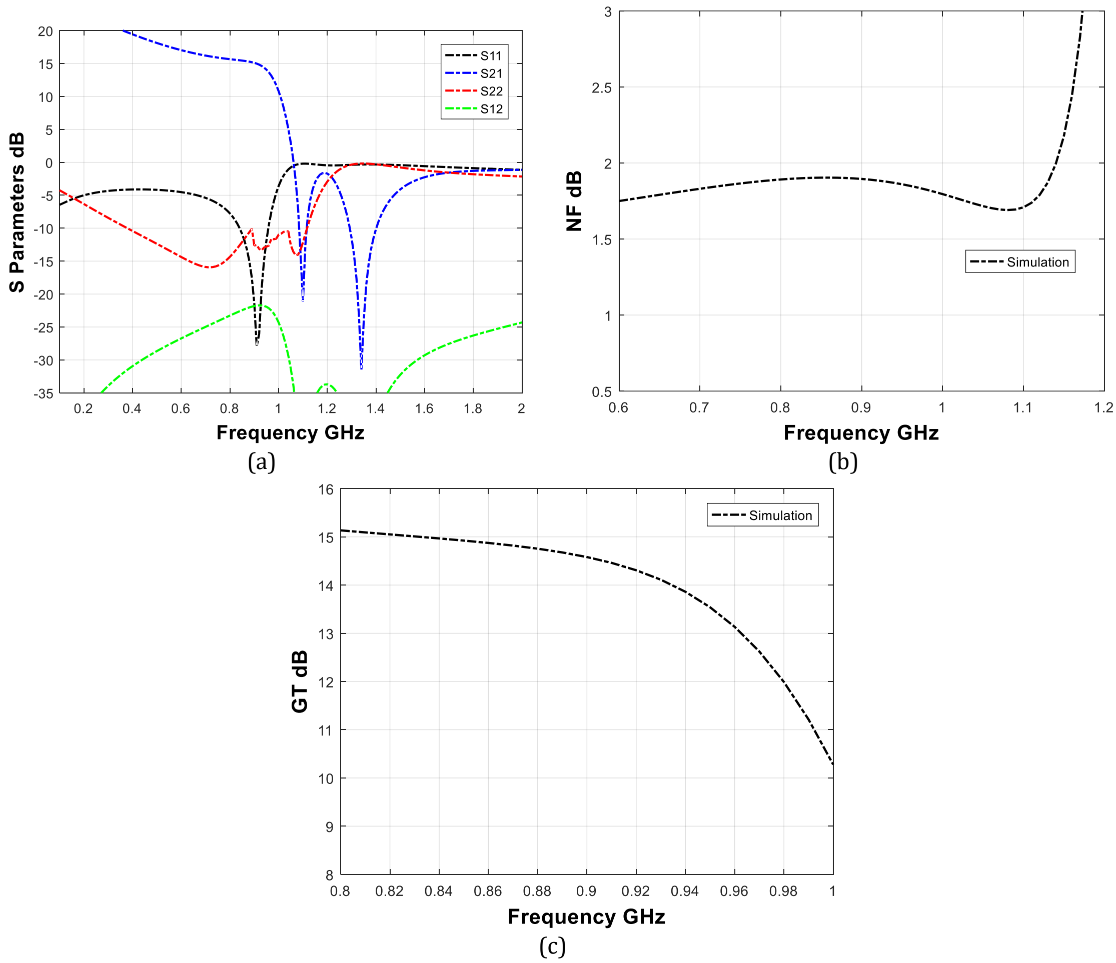

Figure 3. Simulated Performance Of Design LNA (a) Scattering Parameters, (b) Noise Figure, (c) Gain.

Table 3. Simulated Performance of the Proposed LNA Design

Parameter	**Simulated**
Vcc	10V
Operation Frequency [MHz]	900
Noise Figure (dB)	1.8
Gain (dB)	>14
Return Loss (dB)	>25
Output return Loss (dB)	>10
Resonance Frequency [MHz]	900
Power consumption	300mW
Current consumption	60mA
Stability (K)	>1
Size (mm)	42x25

3. Result and Discussion

In this work, the design of a high-performance LNA stage for GSM applications had been achieved using Grey Wolf optimization technique. The main goal of the design is to achieve the requested performance with a single-stage LNA design with the lowest possible noise figure, power consumption, and design size. BFP193W had been used as a high-performance transistor element for the proposed design of LNA. The simulated performance of the LNA is obtained as, a gain level of 14.3 dB, a noise figure of 1.8 dB, and a return loss of less than 15 dB with 33.6 mW power consumption on FR4 material substrate with overall design area of 33x22 mm. The designed LNA achieves a good performance measure at the aimed operation frequency of 900 GHz and preserves its performance over the operation band of 820-980 MHz. thus based on the obtained results the prosed design is a good candidate for GSM band applications.

In this work, design optimization procedure for LNA design using GWO is studied. The used algorithm GWO is surely an efficient method for solution of engineering optimization problems with respect to its back ground on different type of problems. However it is worth mentioning that there might be other algorithms that can present better solutions compared to GWO. In future works, it is aimed to present a detailed analyses of Meta-heuristic optimization algorithm on this study problem and classify their performance based on convergence speed, trapping in local minimal and computationally efficiency rate of algorithms.

Conflict of Interest

No conflict of interest was declared by the authors. Yazarlar tarafından herhangi bir çıkar çatışması beyan edilmemiştir.

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