Optimization of a Microwave Amplifier Using Neural Performance Data Sheets with Genetic Algorithms

Filiz Güneş[1] and Yavuz Cengiz[2]

[1] Yıldız Technical University, Electronics and Communication Engineering Department, Yıldız – Beşiktaş, İstanbul – Turkey , gunes@yildiz.edu.tr
[2] Süleyman Demirel University, Electronics and Communication Department, Isparta -Turkey , ycengiz@mmf.sdu.edu.tr

Abstract. In this work, the neural performance data sheets of the transistor are employed to determine the feasible design target space in the optimization of a microwave amplifier. In order to obtain these data sheets the ANN model of the active device is utilized to approximate the small-signal [S] and noise [N] parameter functions in the operation domain. Inputting of these characterization parameters into the performance characterization of the device results in the triplet of gain G_T, noise F, and input VSWR V_i and its source (Z_S) and load (Z_L) termination functions in the operation domain, from which the neural performance data sheets can be obtained. The genetic algorithms with the binary (BGA) and decimal (CPGA) numbers are utilized in the multi-objective optimization process for the global minimum of the objective function which is expressed as a function only gain of a matching circuit, in the negative exponential form to ensure the rapid convergence . Here optimization of a microwave amplifier with the Π - type matching circuits is given as a worked example and its resulted performance ingredients are compared with the design targets.

1 Introduction

Optimization is one of the fundamental processes frequently encountered in the engineering problems and is highly nonlinear in terms of the descriptive parameters of the system. An optimization process generally contains two fundamental problems:
(i) The first is to form a feasible Design Space which is defined in terms of the design variables and targets; (ii) The second is that the global minimum of the error (objective) function governing the optimization must be obtained with respect to the design variables within the feasible design space.
For optimization of a microwave amplifier, design variables are generally the matching circuit parameters whose lower and upper limits are very often determined by the technology to be utilized in the realization stage of the design. Nevertheless, design targets are still one of the main problems of the amplifier optimization. Generally, the optimization is focused on the transducer power gain (G_T) over a frequency band of operation without controlling the other performance criteria such as the noise (F), the input standing wave ratio (V_i). Certainly, within the optimization process one can

O. Kaynak et al. (Eds.): ICANN/ICONIP 2003, LNCS 2714, pp. 630–637, 2003.

easily embed the desired performance goals without knowing the physical limits and / or compromise relations among F, V_i and G_T appropriately. Unfortunately this process often fails to attain the desired goals. However, the Neural Performance Data Sheets (NPDS) of the transistor overcomes all the above-mentioned handicaps and embeds the compatible (F, V_i, G_T) triplets with their source (Z_S) and load (Z_L) terminations together over a predetermined frequency band of operation. However, a work has recently been completed [1] that gives gain-bandwidth limitations of a microwave transistor whose fundamentals will be focused in the next section. So optimization of a microwave amplifier is a multi – objective design problem with a mix of equality and inequality constraints.

Mathematical nonlinear programming algorithms have emerged as the method of the choice for applications in engineering optimizations problems. The more efficient of this class of methods are generally gradient based, and required at last the first–order derivates of both objective and constrained functions with respect to the design variables. With this “slope-tracking” ability, gradient–based can easily identify a relative optimum closest to the initial guess of the optimum design. There is no guarantee of locating global optimum if the design space is known to be nonconvex. These methods are also inadequate in problems where design space is discontinuous, as the derivatives of both the objective function and constraints may become singular across the boundary of discontinuity.

In engineering design problems, the mix of continuous, discrete and integer design variables has been approached by treating all variables as continuous, and then rounding specific variable either up or down to the nearest integer or discrete variable. This simple rounding procedure often fails completely, resulting in either a suboptimal design, or in some cases, even generating an infeasible design.

Genetic algorithms belong to a category of stochastic search techniques which can work an almost all kinds of design spaces and without any restriction on types of design variables. These algorithms have their philosophical bases in Darwin’s Theory of survival of the fittest. Design alternatives representing a population in a given generation are allowed to reproduce and cross among themselves with bias allocated most fit members of the population. The mechanics of genetic search is to move from a population of designs to another population of designs; these is in contrast to the point to point search available in traditional mathematical programming networks; therefore is highly applicable to the problem search in a nonconvex / disjoint design space with mix of continuous, discrete and integer design variable and offers a better possibility of locating a global optimum. Properties of the genetic algorithm used in the optimization will be given in the optimization section.

2 Neural Performance Data Sheets for a Microwave Transistor

2.1 Neural Performance Data Block Diagram

Neural performance data sheets for a microwave transistor can be obtained from the neural block diagramme given in the Fig.1. According to this block diagramme, this work can be described in three main stages.

In the first stage the signal and noise behaviours of the small–signal transistor are modeled by a Multiple Bias and Configuration, Signal–Noise neural network .So the scattering (S) and noise (N) parameters can result from the output of this neural network as the functions of the Configuration Type (CT), the bias condition (V_{DS} ,I_{DS}) and the operation frequency (f). This part of the work can be considered as the function approximations of the eight scattering and four noise parameters [2,3].

The second stage consists of determining of the compatible performance (F_{req}, V_{ireq},G_{Treq}) triplets and their associated source (Z_{sreq}) and load (Z_{Lreq}) terminations. In this part of the work the performance characterization theory of the transistor is employed, which is given in [4] and [5] using respectively, the impedance [z] and scattering [S] parameter approaches. The input of the second block is the (S) and (N) parameters resulting from the Signal–Noise neural network and the free variables of $F_{req} \geq F_{min}$, $V_{ireq}\geq 1$ and $G_{T\,min} \leq G_{T\,req} \leq G_{T\,max}$.

The second block results in the following triplets and termination data in the operation domain of the device :

$$(F_{req}, V_{ireq}, G_{Tmax}) \Leftrightarrow Z_{Smax}=R_{Smax}+jX_{Smax};\ Z_{Lmax}=R_{Lmax}+jX_{Lmax}$$

$$(F_{req}, V_{ireq}, G_{Tmin}) \Leftrightarrow Z_{Smin}=R_{Smin}+jX_{Smin};\ Z_{Lmin}=R_{Lmin}+jX_{Lmin}$$

$$(F_{req}, V_{ireq}, G_{Treq}) \Leftrightarrow Z_{Sreq}=R_{Sreq}+jX_{Sreq};\ Z_{Lreq}=R_{Lreq}+jX_{Lreq}$$

The third stage of the work is to obtain the neural performance data sheets using the interrelations among the performance measure components F, V_i, G_T and the operation parameters CT, V_{DS}, I_{DS}, f of the transistor. These can give all the necessary information to design a microwave amplifier with optimum performance because the F, V_i, G_T ingredients can be determined only by the active devices in the amplifiers with the lossless and reciprocal matching circuits.

Two approaches can be followed in the utilization of the (F, V_i, G_T) triplet and the Z_S, Z_L functions in the design of the microwave amplifiers circuits :

1. Only the (F, V_i, G_T) triplet function can be employed to provide the design targets over the predetermined bandwidth to the optimization process of the parameters of the front- and back-end matching networks that was recently applied and completed by Aliyev [6].
2. In the second approach only the Z_S, Z_L termination functions can be employed in the design of the front- and back-end matching networks, respectively, to obtain corresponding performance (F, V_i, G_T) triplet over the predetermined bandwidth. This approach is used in this work by combining the genetic algorithm for the data processing in the optimization, which will be given in the

optimization section. Next, a worked example will be given to obtain neural design characteristics for the transistor NE329S01 which is used as the active device of the amplifier circuit.

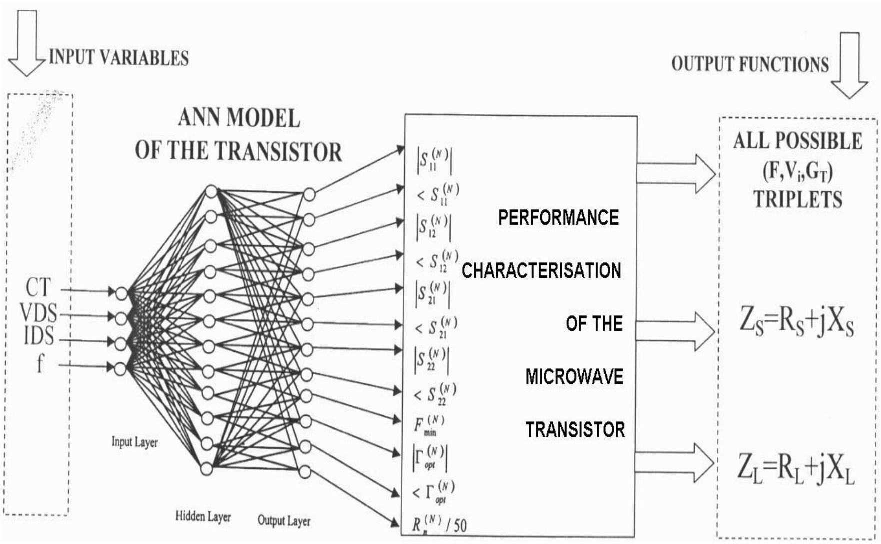
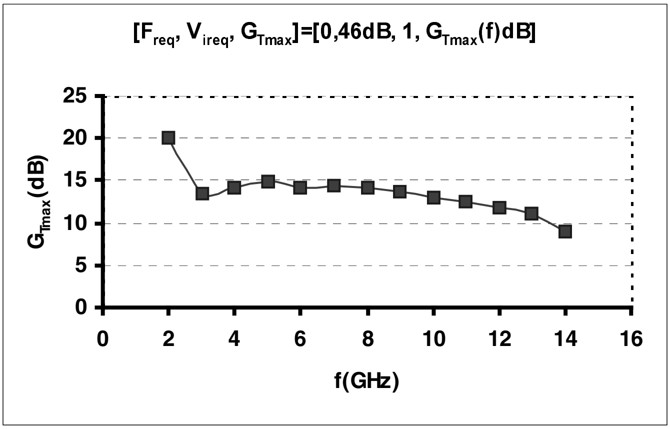


Fig. 1. A Neural Block Diagram of the Performance Data Sheets

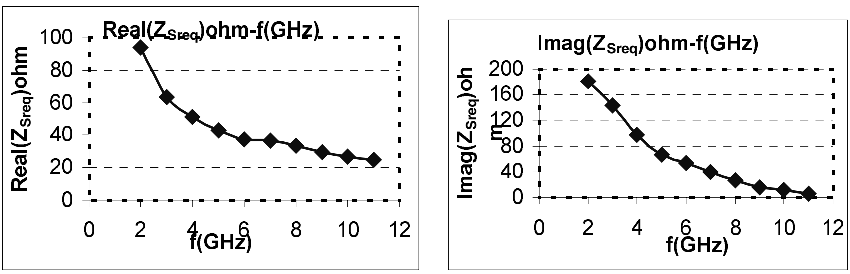
2.2 Worked Example and Design Targets

The characteristics in the Figs. 2 and 3 give respectively, variations of the triplet of (F = 0.46 dB, V_i = 1, G_{Tmax}(f)) and the source (Z_S) and load (Z_L) terminations for the triplet of (F = 0.46 dB, V_i = 1, G_T = 12 dB) of the low noise, high quality transistor NE329S01 biased at V_{CE} = 2 V, I_C = 10 mA with the operation bandwidth 2 – 18 GHz. As seen from the Figs. 3a and 3b, Z_S (ω) and Z_L (ω) functions form a design target subspace that provides an operation with the triplet of F = 0.46 dB,V_i = 1 and G_T = 12 dB over the band of 2 – 11 GHz which cannot go further because of incapability of the transistor.

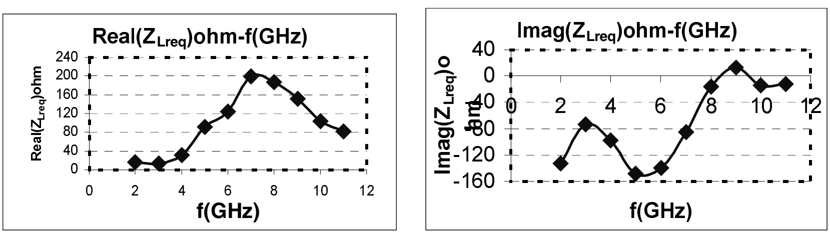


Name of the Transistor: NE 329S01
Bias Condition:
V_{CE} =2 V; I_C= 10 mA
Operation Bandwidth: 2–18 GHz

Fig. 2. [0,46dB, 1, G_{Tmax}(f)] Triplet for the Transistor Ne329s01



(a) Source Termination



(b) Load Termination

Fig. 3. Termination Functions of the (0,46db, 1, 12db) Triplets for the Transistor Ne329s01

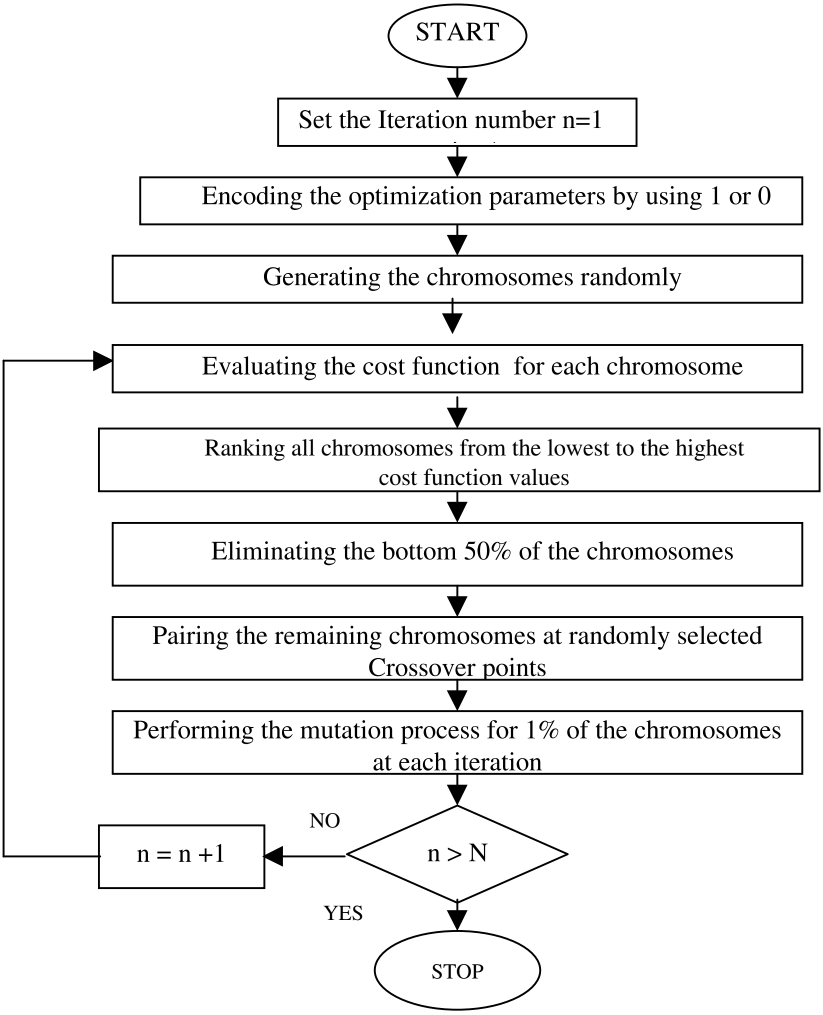


Fig. 4. The flow diagram of the genetic algorithm

3 Optimization Algorithm: Genetic

In optimization of the matching circuits in front and back-ends of the active device, the genetic algorithms with binary (BGA) and decimal (CPGA) coded numbers are used, whose main flow diagram is given in the Fig. 4. Parameters constituting a chromosome are represented by floating-point number in CPGA.CPGA has the advantage of the accurate representation of the continuous parameters also requires less storage and computing time than BGA since it does not need conversion between binary and decimal numbers.

4 Computed Performances and Design Variables

NE329S01 is biased at I_C = 5mA and V_{CE}=10V, for which the termination functions $Z_S(\omega_i)$, $Z_L(\omega_i)$ for $F_{req}(\omega_i)$=0,46dB, $V_{ireq}(\omega_i)$=1,0, $G_{Treq}(\omega_i)$) =12dB, i= 2,…11 are supplied into the optimization process as the target values over the operation bandwidth. These target values are the physically realizable $Z_S(\omega_i)=R_S(\omega_i)+jX_S\omega_i)$; $Z_L(\omega_i)$ = $R_L(\omega)+jX_L(\omega_i)$, i = 2,…11 termination solutions to the simultaneous nonlinear equations of $F\,(R_S, X_S) = F_{req}$, $V_i\,(R_S,X_S,R_L,X_L)=V_{ireq}$, $G_T=(R_S,X_S,R_L,X_L)=G_{Treq}$ for the transistor. Since the optimization process also find out the approximately solution set to the same equations in terms of the predetermined variables, so the resulted values will no longer be equal to the target values, but will be values nearly to the target values, ruled by the objective function and its data processing method. So Figure 5a, 5b and 5c give the resulted $G_T\,(\omega)$,$F(\omega)$, $V_i\,(\omega)$ - frequency variations. Realized bandwidth of the amplifier is between 2 GHz and 11 GHz as expected.

∏-type matching circuit parameters for NE329S01 transistor are found as follows:
ℓ_1 = 14.608cm , ℓ_2 = 13.970cm, ℓ_3 = 0.503cm, $\boldsymbol{Z_{o1}}$ = 85.185Ω , $\boldsymbol{Z_{o2}}$ = 51.995 Ω
$\boldsymbol{Z_{o3}}$ =167.1842 ; ℓ_4 = 14.291 cm , ℓ_5 = 13.678 cm, ℓ_6 = 14.197 cm,
$\boldsymbol{Z_{o4}}$ =199.988 Ω ,$\boldsymbol{Z_{o5}}$ = 114.411 Ω,, $\boldsymbol{Z_{o6}}$ =193.972 Ω (Results of the CPGA)

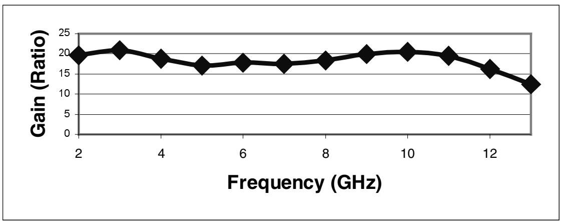


Fig. 5a. G_T (ratio) Variation of the Microwave Amplifier

G_{Treq}(ratio)=15.85
V_{ireq}(ratio)=1.0
F_{req}(ratio)=1.11

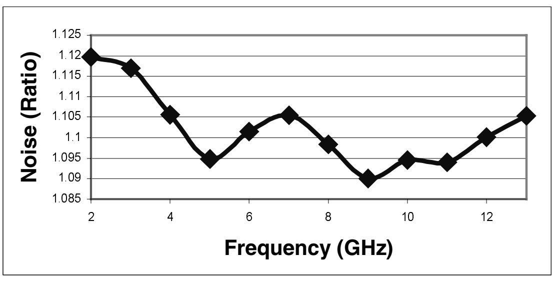


Fig. 5b. Noise (ratio) Variation of the Microwave Amplifier

G_{Treq}(ratio)=15.85
V_{ireq}(ratio)=1.0
F_{req}(ratio)=1.11

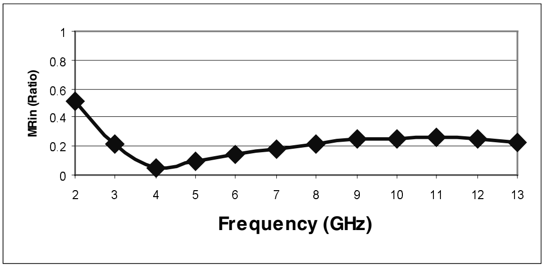


Fig. 5c. Input Reflection Coefficient Variation of the Microwave Amplifier of 5a and 5b.

5 Conclusions

Quality of the microwave amplifier performance can be determined by the flat gain level (G_T) as well as the percent of the maximum power delivered into the input port, which is characterized by the module square of the input reflection coefficient (V_i), over the operation bandwidth. Noise figure (F) is also important performance ingredient depending on the position of the amplifier in system order. In order to have feasible(F, V_i ,G_T) triplets for the design, the potential characteristics of the transistor are obtained from the Neural Performance Data Sheets which are expected to be replaced for the Manufacturers Data Sheets. So the feasible performances of Gain, Input VSWR and Noise Figure can be taken into account simultaneously over the predetermined operation bandwidth in a Multi-Objective Error Function. The global minimum of this Error function are found by BGA and CPGA techniques. The resulted Design Space can be utilized efficiently in the realization by the MMIC (Monolithic Microwave Integrated Circuit) technology.

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