GAAS® 97 • 5th European Gallium Arsenide and related III-V compounds Applications Symposium
Bologna, Italy - September 3rd-5th, 1997

MICROWAVE AMPLIFIER DESIGN USING FUZZY GENETIC ALGORITHM

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Abstract: In this work, a new approach based on fuzzy genetic algorithm for the design of microwave amplifier in a given frequency band with requirements about stability and realizability, in addition to the transducer gain and flatness is presented. Nonuniform transmission lines are used to design input and output impedance matching circuits. An example is also considered.

INTRODUCTION

Generally, input and output impedance matching circuits of a microwave amplifier include a large number of elements such as uniform transmission line sections and stubs. Since the nonuniform lines have the superiority of broader band impedance matching [1], it is possible to design impedance matching circuits with one nonuniform transmission line instead of using a large number of uniform transmission lines and stubs. The global optimization problem in a design process is defined as the problem of finding the global minimum of a given objective or error function depending on many interrelated parameters. Genetic algorithms based on evolution and genetic recombination in nature are known as global optimization algorithms [2]. While traditional optimization techniques based on gradients and/or random searches have the disadvantages of finding local minima instead of global minimum, genetic algorithms have the capability of finding 'global' minimum without any gradient calculation. Genetic algorithms can be fuzzified by extending their gene pool to the whole unit interval [3]. In this work, a new approach based on fuzzy genetic algorithm has been used for the design of stable broadband microwave amplifier consisting of nonuniform transmission line impedance matching sections.

FUZZY GENETIC ALGORITHM AND DESIGN OF MICROWAVE AMPLIFIER

A gene is known as a binary encoding of the parameter of the cost function. A set of genes forms a chromosome subject to reproduction, crossover, and mutation processes. After the cost function is evaluated for each chromosomes, chromosomes are ranked from the lowest to the highest cost function value and unacceptable chromosomes are discarded. This is followed by the crossover operation pairing chromosomes at a random crossover point. Mutation process preventing the system from settling into local minima transforms a small percentage of the bits in the chromosomes from 1 to 0 or visa versa. Although genetic algorithms are known as the best approach [2] while the number of unknown parameters increases, it has been reported that fuzzy genetic algorithms are tend to be more efficient and suitable algorithms than genetic algorithms for some applications[3]. Because genetic algorithms can be fuzzified by extending their gene pool to the whole unit interval [0 1], chromosomes in fuzzy genetic algorithms are coded by the numbers in [0 1] instead of using binary numbers for coding as in classical genetic algorithms [3].

The transducer power gain, G_T, of the amplifier shown in Fig.1 is given by [4]

$$G_T = \frac{4|y_{21}|^2 G_{Sin} G_{Lin}}{|(y_{11}+Y_{Sin})(y_{22}+Y_{Lin}) - y_{12}y_{21}|^2} \qquad (1)$$

where y parameter of the transistor can be denoted by

$$y_{kl} = g_{kl} + jb_{kl} \qquad k,l = 1,2 \tag{2}$$

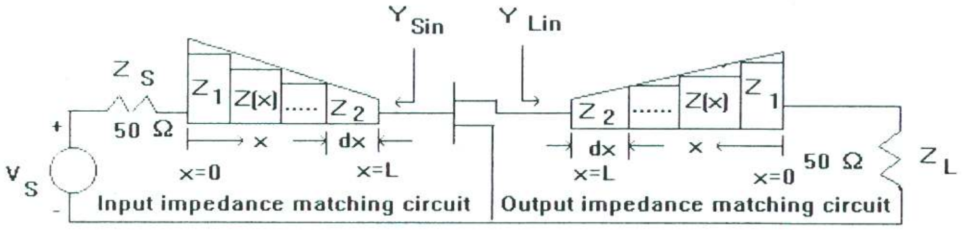


Fig.1. Schematic diagram of the amplifier.

The admittances looking into the nonuniform impedance matching circuits from the transistor Y_{Sin} and Y_{Lin} are given by

$$Y_{Sin}=G_{Sin}+jB_{Sin}, \quad Y_{Lin}=G_{Lin}+jB_{Lin} \tag{3}$$

For all frequencies, the requirements for physical realizability are

$$G_{Sin}\geq 0, \quad G_{Lin}\geq 0 \tag{4}$$

When a potentially unstable transistor is employed, the following inequalities must hold to maintain amplifier stability [4].

$$G_{Sin}+g_{11}>0, \quad G_{Lin}+g_{22}>0 \tag{5a}$$

$$(G_{Sin}+g_{11})(G_{Lin}+g_{22})>(M/2)(1+\cos\theta) \tag{5b}$$

Because g_{11} and g_{22} are positive for most transistors, the stability condition can be replaced by a positive constant K (K>1 for unconditional stability of the amplifier), Stern's stability factor,

$$K = \frac{(G_{Sin} + g_{11})(G_{Lin} + g_{22})}{\frac{M}{2}(1 + \cos\theta)} \tag{6}$$

where M= $|y_{12}y_{21}|$ and θ=phase of $(y_{12}y_{21})$. The input admittance of an exponential line Y_{in} (Y_{Sin} or Y_{Lin}) for a load impedance Z_L (or Z_S)can be calculated from [5]

$$Y_{in} = \frac{Z_1\left[\frac{1}{\lambda_g} + \frac{1}{\lambda_c}\tan\frac{2\pi x}{\lambda_g}\right] + j\frac{Z_L}{\lambda}\tan\left(\frac{2\pi x}{\lambda_g}\right)}{Z(x)Z_L\left[\frac{1}{\lambda_g} - \frac{1}{\lambda_c}\tan\frac{2\pi x}{\lambda_g}\right] + j\frac{Z_1}{\lambda}\tan\left(\frac{2\pi x}{\lambda_g}\right)} \tag{7}$$

where

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\lambda/\lambda_c\right)^2}} \tag{8}$$

and

$$\lambda_C = 4\pi \ln\left(Z_1/Z_2\right) \tag{9}$$

Characteristic impedance distribution of an exponential tapered line is given by [5]

$$Z(x) = Z_1 \left(\frac{Z_2}{Z_1}\right)^{x/L} \tag{10}$$

Z_1, Z_2 and L are used as the variable parameters for optimization. To design a stable broadband microwave amplifier, the error or cost function defined in the following equation is minimized at passband sample frequencies, ωi, using fuzzy genetic algorithm under the physical realizability (4) and stability constraints (5a and 5b).

$$E = \max\left|G_T(\omega_i) - G_o(\omega_i)\right| \qquad i = 1,2,\ldots m \tag{11}$$

Where Go (ω_i) is the desired gain at sample frequencies, while $G_T(\omega_i)$ is the computed transducer power gain from equation (1) for each chromosome. A chromosome consist of characteristic impedances Z_1, Z_2 and the lengths of input and output impedance matching circuits.

NUMERICAL EXAMPLE

The transistor used is HFET-2001 whose scattering parameters and admittance parameters obtained from scattering parameters are given in Table I. The passband is 6-16 GHz. Because its K factor is smaller than 1 below 10 GHz , this transistor is potentially unstable for frequencies in this region.

Frequency (GHz)	**S11** **y11**	**S21** **y21**	**S12** **y12**	**S22** **y22**
6	0.88< -65 0.594 < 83	2 < 125 1.460 < 343	0.05<60 0.0365<278	0.71 < -22 0.2145 < 46
8	0.83 < -85 0.849 < 80	1.81 < 109 1.575 < 337	0.06 < 53 0.0523< 281	0.68 <-30 0.2705 < 54
10	0.79 < -101 1.119 < 77	1.64 < 95 1.720 < 331	0.06 <51 0.063 < 287	0.66 < -37 0.323 < 58
12	0.76 < -113 1.378 < 74	1.48 < 84 1.825 < 325	0.06 < 52 0.074 < 293	0.66 < -43 0.379 < 62
14	0.73 < -126 1.732 < 69	1.39 < 73 2.105 < 317	0.06 <54 0.09 < 298	0.64 < -48 0.42 < 64
16	0.71 < -141 2.272 < 63	1.32 < 61 2.615 < 307	0.06 < 55 0.1386< 301	0.63 < -56 0.479 < 69

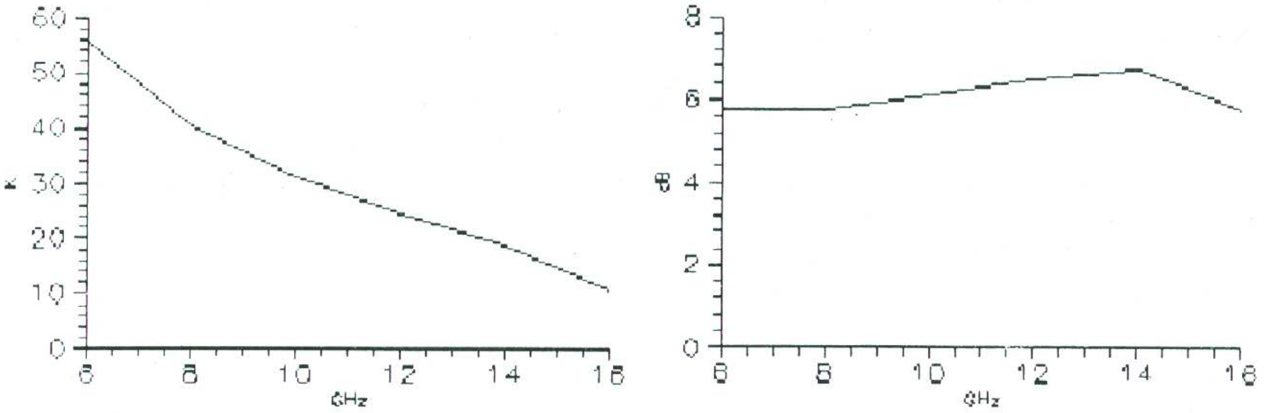
Table I. Scattering and admittance parameters of HFET-2001 (Linear Power Bias : V_{DS}=4V, I_{DS}=50 % I_{DSS})

Each chromosome consists of 12 bits/parameter. The total number of chromosomes is chosen such that it is equal to the total number of bits in a chromosome. After ranking, the bottom 50 % of the chromosomes have been eliminated. Next, the remaining chromosomes have been paired at randomly selected crossover points. Mutation process has been applied for 1% of the chromosomes at each iteration. The algorithm has been run for 25 iterations. The search interval for characteristic impedances Z_1 and Z_2 have been chosen as $20\Omega \leq Z_{1,2} \leq 120\Omega$ while the search interval for the lengths of input and output nonuniform microstrip lines with $\varepsilon_r = 9.8$ have been chosen as $1\ \text{mm} \leq L \leq 5\ \text{mm}$. Sample frequency points have been selected as 6, 8, 10,12, 14 and 16 GHz respectively. The results of the fuzzy genetic algorithm is given in Table II.

Input impedance matching circuit			**Output impedance matching circuit**		
$Z_1(\Omega)$	$Z_2(\Omega)$	L (mm)	$Z_1(\Omega)$	$Z_2(\Omega)$	L (mm)
23	64	1.482	53	119.89	1.347

Table II. Line parameters after optimization.

The goal for optimization was to approximate the flat gain level (Go) 7.5 dB over the passband. The transducer power gain performance of the overall amplifier is 6.27 ± 0.53 dB. The transducer gain and stability factor are shown in Fig.2a and 2b respectively. For comparison, the amplifier using the same HFET-2001 transistor with 2 elements for the input impedance matching circuit and 3 elements for the output impedance matching circuit designed by Yarman using Supercompact had a gain of 6.81 ± 0.57 dB [6].



(a)

(b)

Fig. 2 **(a)** Stability factor of the amplifier **(b)** Transducer power gain of the amplifier

CONCLUSION

By new approach input and output impedance. matching circuits of the microwave amplifier are designed using nonuniform microstrip lines. Design method takes gain flatness, amplifier stability and realizability into account simultaneously. New approach doesn't require any gradient information so that it can be implemented easily. Thus, fuzzy genetic algorithm is suitable for the synthesis of linear or nonlinear microwave circuits.

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