

Design Active Filter Based on Genetic Algorithm

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Abstract

The lossy-FDNR based active filter has an important property among many design realizations. This includes a significant reduction in component count particularly in the number of OP-AMP which consumes power. However the problem of this type is the large component spreads which affect the filter performance.

In this paper Genetic Algorithm is applied to minimize the component spread (capacitance and resistance spread). The minimization of these spreads allow the filter structure to be integrated since the minimum component spread mean minimum chip area required for fabrication.

Introduction

In this paper, the design and synthesis of a class of analog integrated circuits using Genetic Algorithms are presented. The design includes the design and realization lossy FDNR type integrated circuit filters. The design involves optimizing certain parameters and satisfies the required specified characteristic. The realized circuits are simulated using EWB (Electronic work Bench), and compared these results traditional optimization method.

The FDNR filters are certain types of filters that are designed using a different strategy from the RLC traditional filters like the low pass filter (1, 2).

The principle is to realize lossy FDNR structure obtained via bruton transformation of lossy RLC prototype. The FDNR has the

impedance $\frac{1}{Ds^2}$ that means the impedance is inversely proportional to the square of the frequency. Of course, the implementation of such an element needs active elements.(Op Amps).

Usually the parallel combination of a D element a capacitor which is called lossy FDNR is implemented using an Op Amp, resistor and two capacitors, as shown in fig.(1)(3).

The use of lossy FDNR structure saves component count particularly the number of Op-Amps. However the resistance and capacitance spread are too large. Since there is a large margined of freedom is available with the design of the parameter values, classical optimization (4) is used to select these values. The problem of using classical optimization is that this technique search may stick in some regions depending on the type of function and equations. Another limitation is that as the optimization routine becomes more complicated.

This paper employs the genetic algorithm as a search technique. This technique solves the complication arise in higher order structure as well as provide design with minimum component spread.

Genetic Algorithm in Electronic

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. In GAs, the search is divided into generations each generation consists of a number of individuals and each individual describes the problem parameters that should be optimized (5). The main advantage of GAs over traditional optimization techniques is that they are used in situations in which no analytical formulation can be found for the mathematical description of the problem (6, 7).

One of the relatively new and important applications for GAs is the design and synthesis of electronic circuits (8). This application suits GAs very much because designing electronic circuits is a problem that involves optimizing a very large number of parameters. For example to design a filter or an Op Amp we need to specify the values of tens of elements like resistors, capacitors, the parameters of the transistors and diodes in addition to determining the way these elements are connected together. To reduce the cost of the design, one has to reduce the number of components (in the case of discrete

elements' implementation) and their area (in the case of implementing the circuit using ICs), and at the same time obtain good performance regarding the frequency and phase response for the filter and the gain, bandwidth, slew rate, and other parameters for the Op Amp (4), response times, fan in, and fan out in the case of digital circuits. Since solving this problem using traditional maximizing and minimizing techniques is almost impossible, GAs arises as the best solution.

The use of genetic algorithms in electronics is very important now as the electronic industry is evolving and almost all circuit all design becoming automated. The main reason why Genetic Algorithms are very successful in electronics is that most electronic system design tasks deal with nonlinear equations that are usually not suitable for example, each transistor has a nonlinear relation between voltages and current and usually this relation is different in different regions of operation ^[10]. For example, the equation is different in the active region from the one in the saturation region. The traditional design techniques will not be systematic in these cases and will rely mainly on trial and error principle.

The main issue in GAs in electronic circuit design is that how the chromosome will describe the circuit. The design starts by defining the parameters for encoding in the chromosomes. These parameters determine the circuit behavior. For example a certain design contains three resistors and three capacitors then the chromosome should include the values of the six parameters. The number of bits used for each parameter is determined based on the acceptable range for that parameter and the resolution, i.e. the increment between two consecutive values.

Design and Simulation of Lossy FDNR Based on Genetic Algorithm

Genetic algorithm is employed here to minimize the component spread for the lossy FDNR-structures. A third order realization is taken as an illustrative example. A direct realization of a Low Pass Chebyshev filter with 3 KHz cutoff frequency and 0.5 dB ripple factor is presented. The design is based on the FDNR concept. The GA is employed to find the optimum values of resistors and capacitors that satisfy the given frequency response (cutoff frequency) and reducing

simultaneously the resistance and capacitance spreads. The minimization of these spreads is very important factor for reducing the chip size.

$$R_{\text{spread}} = \frac{R_{\text{max}}}{R_{\text{min}}} \dots\dots\dots [1]$$

$$C_{\text{spread}} = \frac{C_{\text{max}}}{C_{\text{min}}} \dots\dots\dots [2]$$

These spread formulates the fitness for each chromosome depend on the reciprocal of the sum of the resistance and capacitance spreads as follows:

$$\text{fitness} = \frac{1}{R_{\text{spread}} + C_{\text{spread}}} \dots\dots\dots [3]$$

The lossy FDNR structure active realization is derived from the standard transfer function and implemented using the traditional RLC techniques. The normalized standard equation is given from tables as follows [11].

$$\frac{Vo(s)}{Vi(s)} = \frac{0.716}{s^3 + 1.253s^2 + 1.535s + 0.716} \dots\dots\dots [4]$$

The equation coefficients are related to the coefficients obtained from the circuit transfer function of fig.(3-C) after the Bruton transformation is applied.

$$\frac{Vo(s)}{Vi(s)} = \frac{\frac{1}{DR_1R_2C_2}}{s^3 + \left(\frac{R_1R_2C_2C_1 + DR_1}{DR_1R_2C_2}\right)s^2 + \left(\frac{R_1C_1 + R_1C_2 + R_2C_2}{DR_1R_2C_2}\right)s + \frac{1}{DR_1R_2C_2}} \dots [5]$$

The result of comparison is a set of non-linear equations that should be solved together to obtain the required filter specifications. These equations showed a margin of freedom in the parameter values.

$$\omega_c - \sqrt[3]{\frac{1}{0.716R_1R_2R_3C_2C_3C_4}} = 0 \dots\dots [6]$$

$$\omega_c - \sqrt{\frac{1.253}{0.716(R_1R_2C_2C_3 + R_1R_2C_2C_4 + R_1R_3C_3C_4)}} = 0 \dots\dots [7]$$

$$\omega_c - \frac{1.535}{0.716(R_1C_2 + R_1C_3 + R_1C_4 + R_2C_2)} = 0 \dots\dots [8]$$

where:

$$C_1 = C_3 + C_4$$

$$D = C_3C_4R_3$$

The third order circuits before and after the transformation are shown in fig. (2) and the lossy FDNR realization of the 3rd order filter considered is shown in fig. (3).

Since the circuits consist of three resistors and three capacitors, then the chromosome should be divided into six parts, each encoding the value of one of the elements in the design. Twenty bits are used to encode the value of each element giving a total of 120 bits. The number of bits chosen is based on the range of values and resolution for the resistors and capacitors. The selected range of resistors is to be between $10k\Omega$ to $10m\Omega$ with a step size of $1ohm$ so the total number of possibilities will be $(10 \times 10^6 - 10 \times 10^3)$ which is approximately equal to 10×10^6 . 10×10^6 means 20 bits since 2^{20} equals approximately 10×10^6 . For the capacitors the ranges are between 10×10^{-12} and 10×10^{-6} F with a step size of 10×10^{-12} which also needs 20 bits.

Table (1) shows the last generation values of these parameters.

From the above table it can be seen that the realized filter has minimum resistance and capacitance spread compared with that obtained by optimization or traditional techniques [4]. Beside that the circuit frequency characteristics is preserved as shown in fig. (4). the

simulated frequency response shown in fig. (4) is obtained using EWB.

Fifth Order FDNR Filters

A more complicated structure is also investigated. A fifth order Chebyshev type is designed using the same procedure. Table (2) present the component spreads while fig. (7) shows the simulated response.

$$\omega_c - \frac{C_4 + C_5}{0.224R_4C_4C_5} = 0 \quad [11]$$

$$\omega_c - \frac{C_6 + C_7}{0.5865R_5C_6C_7} = 0 \quad [12]$$

$$\omega_c - \sqrt{\frac{1}{1.03587R_1R_4C_4C_5}} = 0 \quad [13]$$

$$\omega_c - \sqrt{\frac{1}{0.47678R_2R_5C_6C_7}} = 0 \quad [14]$$

$$\omega_c - \frac{1}{0.36R_3C_3} = 0\Omega \quad [15]$$

where

$$D_1 = R_4C_4C_5$$

$$D_2 = R_5C_6C_7$$

$$C_1 = C_4 + C_5$$

$$C_2 = C_6 + C_7$$

The fifth order circuits before and after the transformation are shown in fig. (5) and the lossy FDNR realization of the 5th order filter considered is shown in fig. (6).

Conclusions

This paper is concerned with design and realization of lossy-FDNR active filter circuits based on using genetic algorithm concept. The main objective of the design method for this type is the minimization the chip area required for fabrication. In analog type circuit the chip area is related to the component spread, therefore the component spread has been the objective function that has be minimized. While in digital IC the chip area is determined by transistors aspect ratio, this is then the function of this minimization procedure. Genetic algorithms are realized to minimize the chip area required while sustaining the other performances such as frequency characteristic, transfer curve, etc'. To conclude the objectives of this work the following points are presented.

1. GAs is in general more suitable to the problem of electronic circuits design and synthesis than a traditional technique like Newton-Raphson method that works on approximate and trial and error solutions.
2. The advantage of GAs over traditional techniques is that it is more suitable for complicated structure. i.e. large set of equations with larger number of parameters, nonlinearities and nonsystematic equations. This result is concluded based on comparing the results of FDNR based filters for the 3rd and the 5th orders with the traditional techniques. The difference in the mean spread is 0.0468 in the 3rd order filter while it is 3.8072 for the case of 5th order filter. So when the problem becomes more difficult, the GA advantages become clearer.

An EWB simulation of the realized filter agrees with that specified as shown in fig. (7).

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Table (1). The third order filter best values.

Parameter	Value
R1	44.6 kΩ
R2	424 kΩ
R3	584 kΩ
C2	0.181 nF
C3	0.323 nF
C4	0.323 nF
Resistance Spread	13.09
Capacitance Spread	1.78

Table (2). The fifth order filters best values.

Parameter	Value
R1	7.143kΩ
R2	56.7kΩ
R3	263kΩ
R4	591kΩ
R5	315kΩ
C3	0.557 nF
C4	0.777 nF
C5	0.829 nF
C6	0.557 nF
C7	0.593 nF
Resistance Spread	82.71
Capacitance Spread	1.49

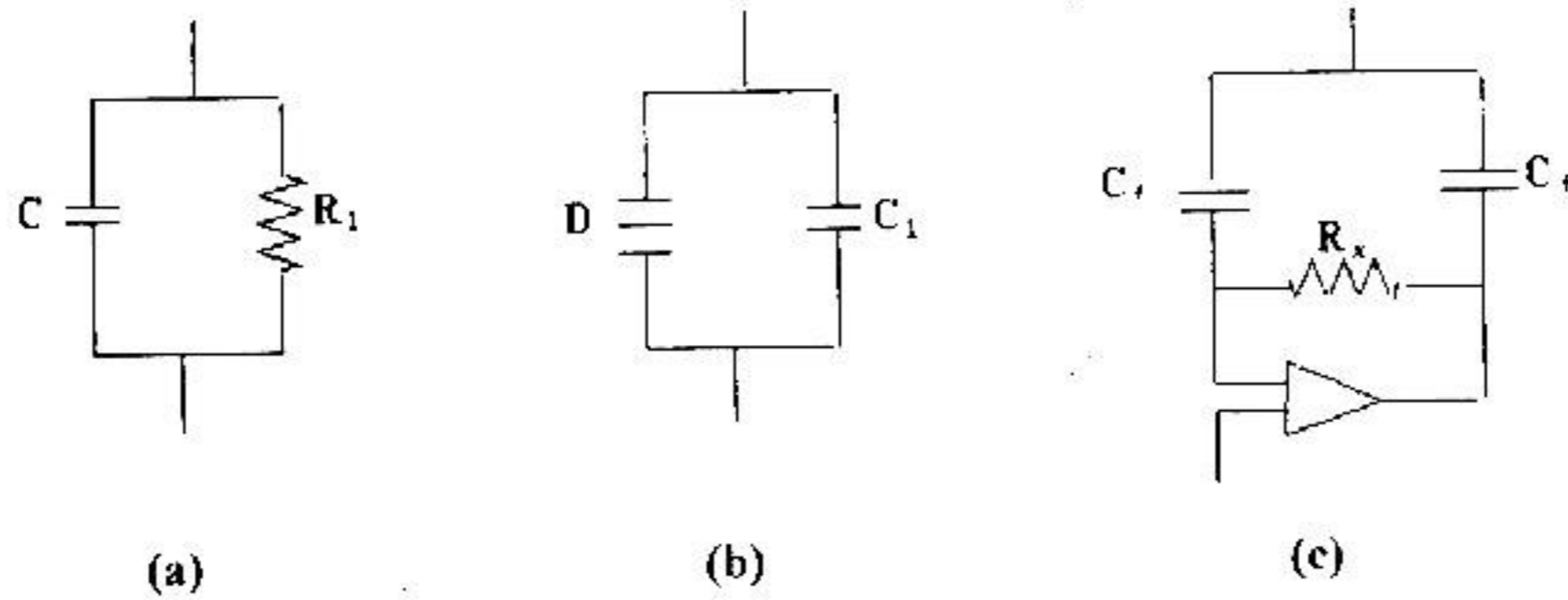


Fig. (1) (a) Lossy capacitor subcircuit
 (b) Bruton transformation of (a) (FDNR-C subcircuit)
 (c) Simulated FDNR-C subcircuit

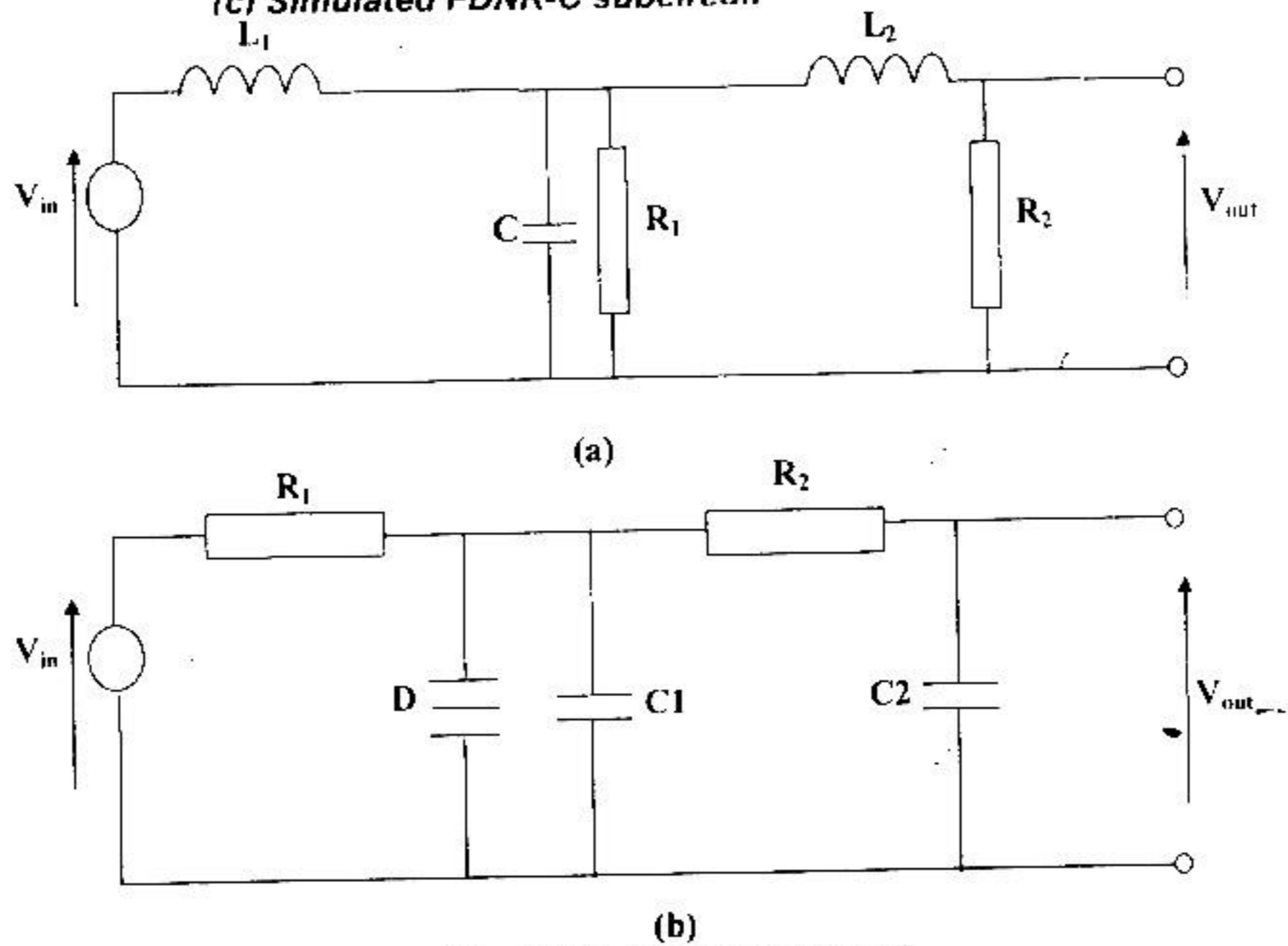


Fig. (2) (a) General RLC LPF
 (b) Bruton transformation of (a)

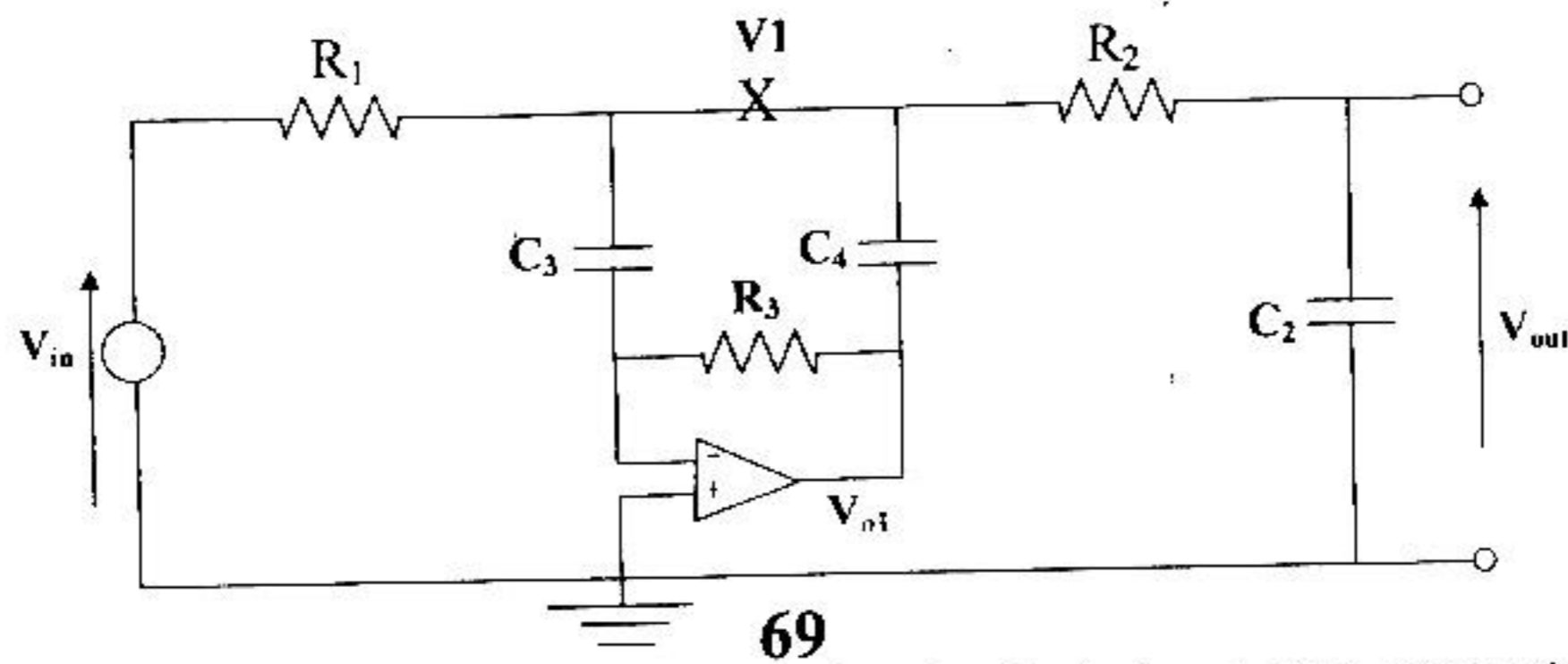


Fig. (3) FDNR-RC realization of 3rd order singly-terminated, Chebyshev LPF

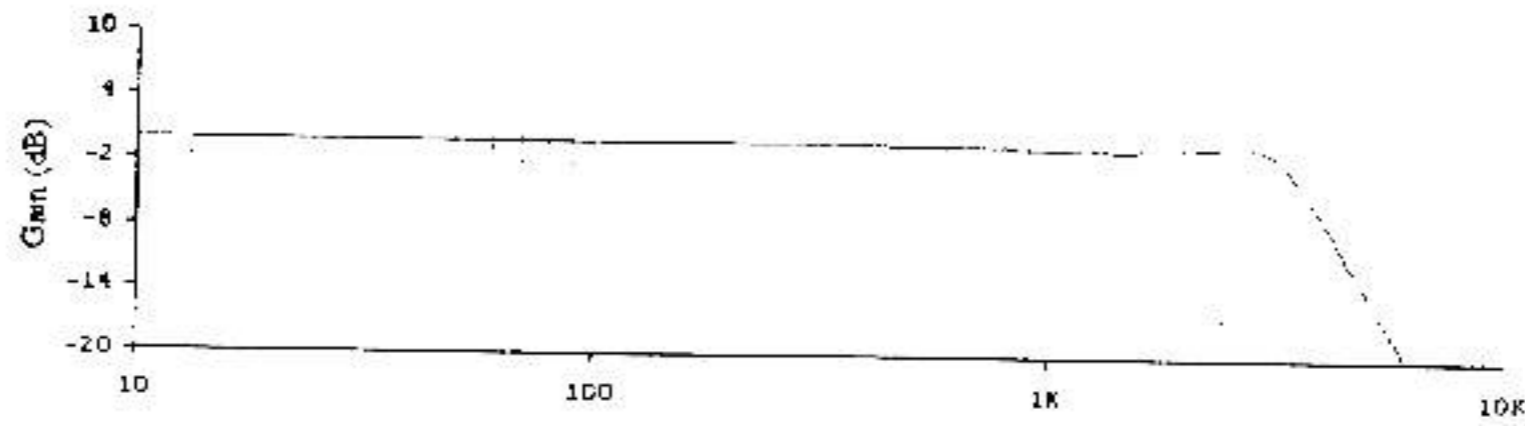
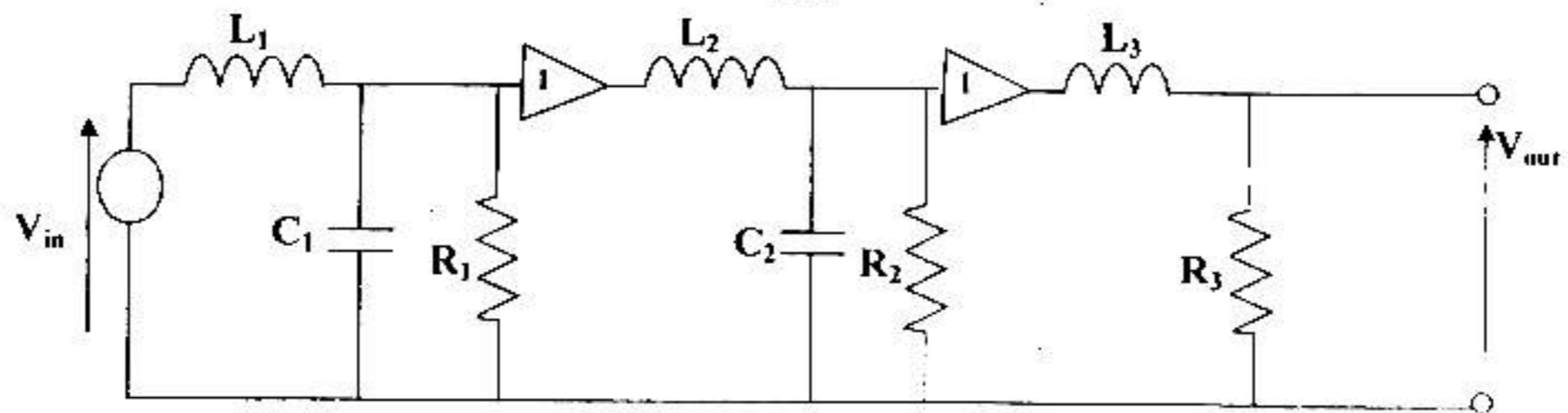
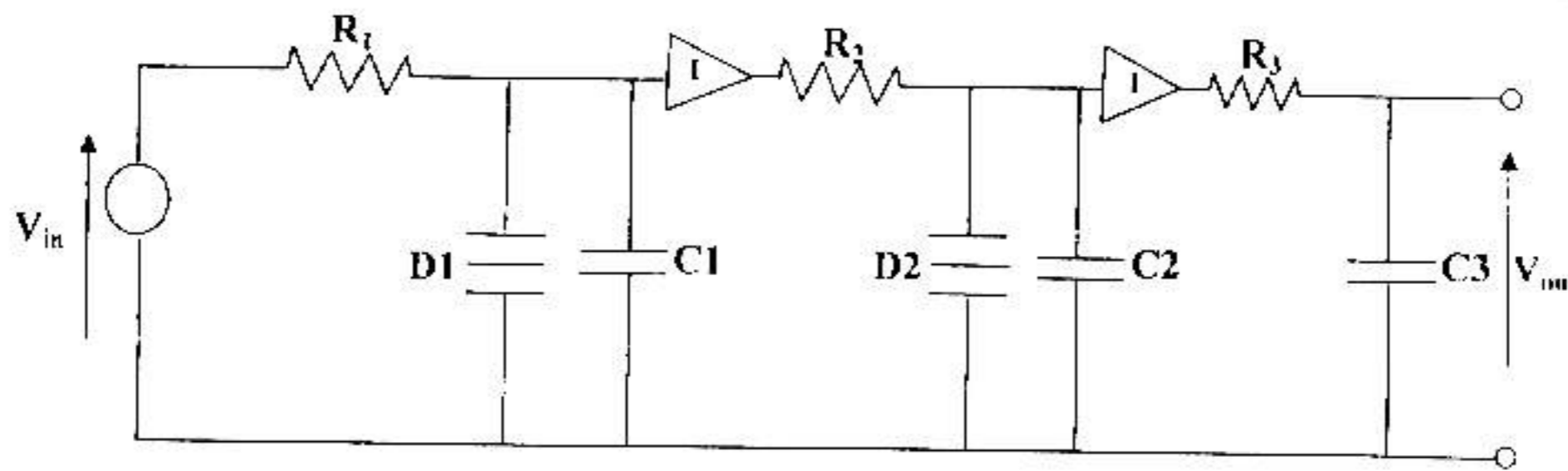


Fig. (4) The frequency response of the third order filter designed using GA



(a)



(b)

Fig.(5) Cascaded of 5th order, singly - terminated, Chebyshev LPF
(a) RLC lossy prototype
(b) Bruton transformation of (a)

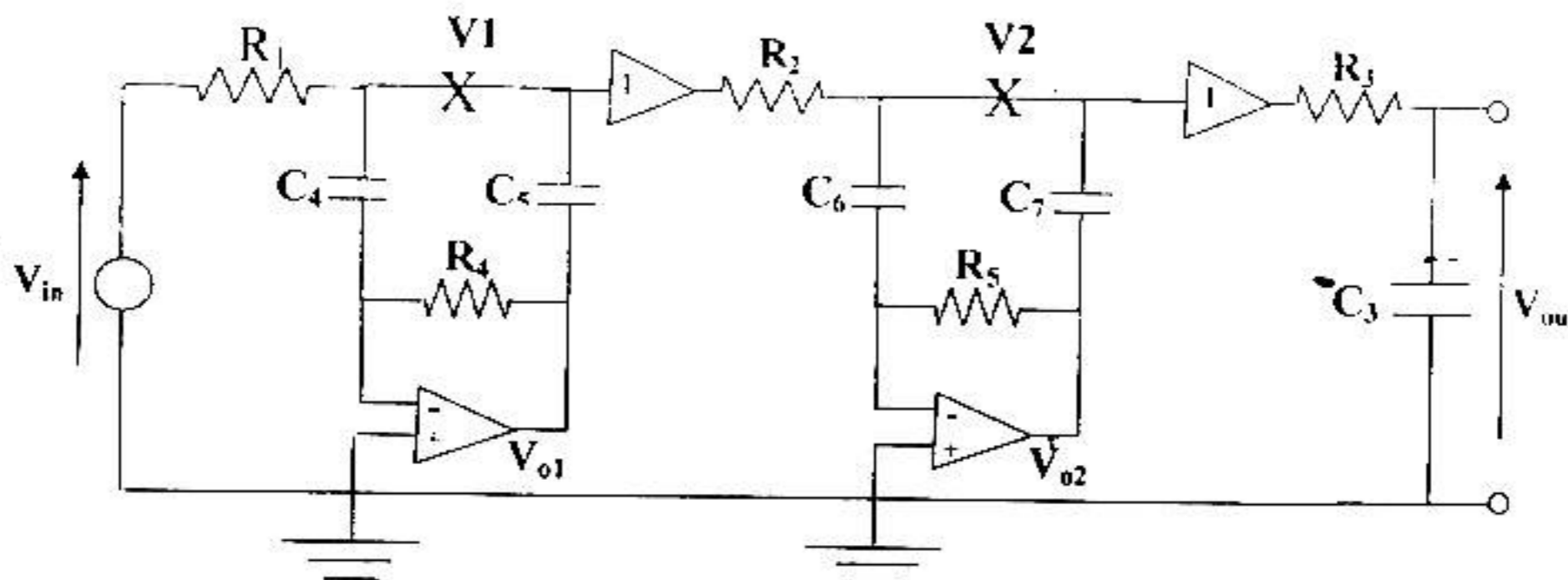


Fig. (6) FDNR-RC realization of 5th order singly-terminated Chebyshev LPF

List of Simples

OP-AMP	Operational amplifier
RLC	Resistance inductance capacitance
FDNR	Frequency dependent negative resistance
GAs	Gallium arsenide
EWB	Electronic work bench

تصميم مرشح فعال يعتمد على خوارزمية (Genetic Algorithm)

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الخلاصة

المرشح نوع (Frequency dependent negative resistance) المبني على مبدأ المرشح الفعال يمتلك خواصا مهمة وضرورية في التصميم . وهذه الخواص تقوم بتقليص عدد العناصر المستخدمة عمليا في دوائر مضخم العمليات التي تستهلك القدرة . في هذا البحث استعملت خوارزمية نوع (Genetic Algorithm) لتقليص عدد العناصر المنتشرة في الدائرة مثل (المتسعات والمقاومات)، وان هذا التقليل في انتشار العناصر ساعد في تركيب المرشح على شكل دائرة متكاملة تشغل مساحة صغيرة في التصنيع .