An intelligent Technique for Generating Equivalent KHN Circuits using Genetic Algorithm

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***Abstract*— Genetic algorithm applications in analog design circuits play an important role with promising results. This paper introduces the GA methodology and employs KHN circuit as an application. It is an intelligent technique for generating equivalent KHN Circuits using genetic algorithm with nullor and mirror elements. The goal is to generate equivalent KHN circuits using Second Generation Current Conveyor (CCII) as well as equivalent Trans-conductance Amplifier (TA) circuits. This methodology generates 32 different KHN-CCII circuits for type A and type B. Moreover, it generates 64 KHN-TA circuits for each type. The frequency response of one of the generated KHN circuits are compared to the conventional op-amp one using PSPICE and it is proved that the generated circuits have superior performance. It is worth noting that the great advantage of the proposed GA technique is to get all realizable solutions programmatically and it is a universal technique that can be applied on any filter.**

Keywords—KHN filter; Genetic Algorithm; nullor; mirror elements; CCII circuits; TA circuits.

I. INTRODUCTION

The symbolic analysis is a powerful tool to analyze electronic circuits, where all parts of the circuit elements are considered to be symbols. The nullor is quite useful for the analysis, synthesis, and design procedures, as it facilitates modeling the behavior of any active device disregarding the particular realization of the active blocks [1]-[6].The CCII+, ICCII+ and ICCII− can't be realized using the nullator norator combinations only as demonstrated in [1],[2]. Therefore, The pathological VM and the pathological CM which introduced in [3],[4] provided means of representing the four single-output CCII and ICCII members without any need to use resistors [3]. The systematic synthesis of active circuits extended in [7],[8] to accommodate the pathological mirror elements allowed ideal representations of active circuits. In [9]-[11], synthesis methodologies based on genetic algorithms (GAs) have been introduced.

The Genetic Algorithm (GA) is such an optimization technique which operates based on the principle of "survival for the fittest". GA has the capability of generating new designed solutions from a population of existing solutions, and discarding the solutions which have an inferior performance or fitness [9]. For instance, Esteban et al., designed voltage followers (VFs) and voltage mirrors (VMs) circuits by performing evolutionary operations [10] as well introduced synthesis CCII by superimposing VFs and current followers (CF) based on genetic operations techniques [11]. Also, Mourad et al., design voltage followers (VFs) circuits using genetic algorithms with nullator-based descriptions [9]. Soliman uses Nodal Admittance Matrix (NAM) expansion to generate a family of KHN circuits through CCII block [12],[13].

The KHN filter [14],[15] provides the three basic filtering functions namely the high-pass (HP), band-pass (BP) and low-pass (LP) responses simultaneously at three different outputs. The circuit uses three op-amps as shown in Fig. 1. There are two types of KHN filter, type A and type B, depending on where to apply the input voltage. This paper introduces a new methodology based on nullor and mirror elements and applies for KHN filter to generate the equivalent circuits by applying genetic operations instead of using NAM. In this work, all possible circuits are generated programmatically employing the KHN-GA. The KHN-GA technique uses high-frequency CCII and TA blocks which cannot be achieved using op-amps. It is an intelligent technique for realizing equivalent KHN circuits using genetic algorithm with nullor and mirror elements. The goal of the KHN-GA Technique is to employ the genetic operations which first used to generate CCII-KHN and TA-KHN equivalent circuits.

This paper is organized as followed; the methodology is described in section II. In section III, the methodology is applied on KHN-GA using TA blocks. Finally, section IV concludes the work.

II. METHDOLOGY

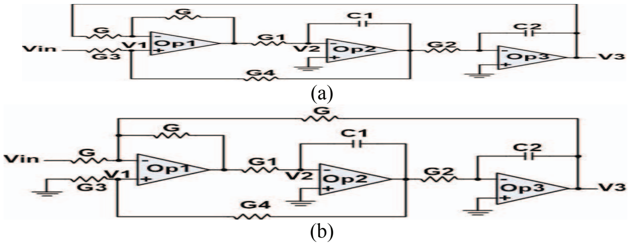
The proposed algorithm of the GA is carried out in steps as shown in Fig. 2. First, the nodal equation for the circuit is to be written in the form of [Y] [V] =0. Then, all the passive elements are encoded in genes. Each element is represented by a gene in the form $\mathrm{Gen{:}\,R \cdot C \cdot S}$, where R represent the row number, C represent the column number, and S represent the sign bit which is 1 for positive elements while it is equal to 0 for negative elements. Considering that if the column and row numbers are equal, the element is grounded and it is represented for simplicity by $\mathrm{Gen{:}\,R \cdot 0}$ otherwise an expansion subroutine for the element is applied.

Third, the number of passive elements is defined in the Y matrix which represent the total number of elements of the circuit, a single increment of the number of rows represent the number of original nodes which is represent the input node, the number of diagonal elements represents the number of grounded passive elements, and the left elements are thus the floating passive elements. Then, the floating passive elements are expanded as follows; the encoding of the nullor and mirror elements shown in Table I to encode the CCII and TA families is employed.

The used current conveyor types in this work are CCII+, CCII-, ICCII+, and ICCII- which are presented in [7], [8],[16]. These current conveyors can be codified in genes using the encoding as shown in Table I. The gene codification of the four considered types of the current conveyor is finally given in Table II.

The realizations of different types of TA based on nullor elements and pathological mirror elements was employed in [17], [18]. In this work, Single Output TA (SO-TA) will be considered. To facilitate dealing with SISO-TA in the proposed algorithm, each one can be codified in genes by the encoding shown in Table I. The gene codification of positive resistances can be obtained using the first and the second configurations while negative resistances can be obtained using the third and fourth configurations as shown in Table III.

A subroutine for the floating elements is to be applied. The elements are expanded based on the sign bit (S). If S is 1; which means that it is the positive element, thus the gene is written as $\mathrm{Gen}|_{\text{Passive element}} = \mathrm{R \cdot N \cdot P \cdot N \cdot C \cdot O}$ Or $\mathrm{Gen}|_{\text{Passive element}} = \mathrm{R \cdot N \cdot I \cdot N \cdot C \cdot V}$ where N is the insertion node. On the other hand, if S is 0; which means that it is the negative element, so, the gene is written as: $\mathrm{Gen}|_{\text{Passive element}} = \mathrm{R \cdot N \cdot I \cdot N \cdot C \cdot O}$ Or $\mathrm{Gen}|_{\text{Passiveelement}} = \mathrm{R \cdot N \cdot P \cdot N \cdot C \cdot V}$ the generated genes of the passive elements are then compared to that of the active counterpart. The generated circuit is then tested for the optimum ω_0 and Q.The genes then are arranged together to form a chromosome. The mutation (bit inversion) is then made to the genes resulted from the subroutine described before. The mutated genes and the genes of the active elements are also compared. The performance of the generated circuits is also tested for optimum ω_0 and Q. Further circuits can also be generated by crossing over the genes which have the same sign. Mutation and crossover are carried out for the rest of the genes. The total number of generated circuits from that procedure is $2^{\text{no.floatingelements}}$.



(a)

(b)

Fig. 1. (a)Type A KHN circuit using three op amps [14]. (b) Type B inverted KHN circuit using three op amps [15].

TABLE I. GENE CODIFICATION OF THE NULLOR AND MIRROR ELEMENTS

Nullor	Genetic representation	Mirror Elements	Genetic representation
Nullator	O	Voltage mirror	V
Norator	P	Current mirror	I

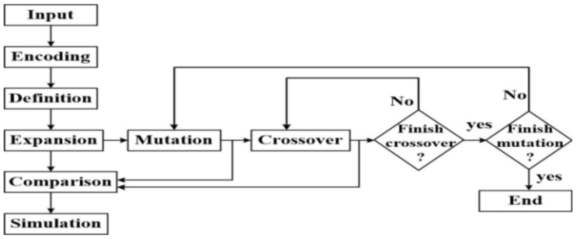


Fig. 2. Flow chart for the proposed algorithm

TABLE II. GENE CODIFICATION OF THE CCII FAMILY

CCII Name	Genetic Representation	ICCII Name	Genetic Representation
CCII+	Z.X.I.X.Y.O	ICCII+	Z.X.I.X.Y.V
CCII-	Z.X.P.X.Y.O	ICCII-	Z.X.P.X.Y.V

TABLE III. GENE CODIFICATION OF THE TA FAMILY

TA name	Genetic Representation
TAI-	Gen | = U.S.P.S.M.O Gen | = U. S. I. S. M. V
TAO-	Gen | = U. S. P. S. N. O Gen | = U. S. I. S. N. V
TAI+	Gen | = U. S. I. S. M. O Gen | = U. S. P. S. M. V
TAO+	Gen | = U. S. I. S. N. O Gen | = U. S. P. S. N. V

III. GENERATING TA-KHN EQUIVALENT CIRCUITS USING GA

The nodal equations for the KHN-GA Type B realization shown in Fig. 1(b) can be written as follows:

$$G_1V_1 + sC_1V_2 = 0 \tag{1}$$

$$G_2V_2 + sC_2V_3 = 0 \tag{2}$$

$$(G_3+G_4)V_1-3G_4V_2+(G_3+G_4)\,V_3+(G_3+G_4)\,V_{IN}=0 \tag{3}$$

A. Different realizations of KHN Circuit using TA

The proposed methodology is applied to the KHN-GA circuit type B configuration as follows:

Step 1: write the nodal equations for this circuit which are given in (1), (2) and (3).Then, put these equations in the form:

$$Y=\begin{bmatrix} G_3+G_4 & -3G_4 & G_3+G_4 G_3+G_4 \\ G_1 & sC_1 & 0 & 0 \\ 0 & G_2 & sC_2 & 0 \end{bmatrix} \tag{4}$$

Step 2: Encode all the elements in genes form

$\mathrm{Gen1}|_{G_3+G_4(g)}$= 1.1.1. $\mathrm{Gen2}|_{G_3+G_4(f1)}$ = 1.3.1

$\mathrm{Gen3}|_{G_3+G_4(f2)}$ = 1.4.1. $\mathrm{Gen4}|_{-3G_4}$ = 1.2.0

$\mathrm{Gen5}|_{G_1}$ = 2.1.1 $\mathrm{Gen6}|_{sC_1}$= 2.2.1

$\mathrm{Gen7}|_{G_2}$= 3.2.1 $\mathrm{Gen8}|_{sC_2}$ = 3.3.1

For the first, the row No. equals to the column No. for the sixth and the eighth genes. So, they are transferred to the output file as follows:

$G_3 + G_4(g)$ 1 0 C_1 2 0 C_2 3 0

The grounded resistance is represented using TA as shown in Fig. 3 [19], [20]. Here, the realization of Fig. 3(a) is utilized.

(a) (b)

Fig. 3. Representation of grounded resistance using TA [19, 20]

Step 3: extract the No. of elements which is equal to 8.

No. of original nodes = 3+1=4.

No. of grounded elements = No. of diagonal elements = 3

No. of floating elements = No. of additional nodes = 8 – 3 = 5.

The expansion subroutine is applied to the rest of genes as follows:

$\mathrm{Gen4}|_{-3G_4}$ =1.5.O.5.2.I
Or $\mathrm{Gen4}|_{-3G_4}$=1.5.V.5.2.P
$\mathrm{Gen3}|_{G_3+G_4(f2)}$=1.7.O.7.4.P
Or $\mathrm{Gen3}|_{G_3+G_4(f2)}$=1.7.V.7.4.I
$\mathrm{Gen7}|_{G_2}$=3.9.O.9.2. P
Or $\mathrm{Gen7}|_{G_2}$=3.9.V.9.2.I

$\mathrm{Gen2}|_{G_3+G_4(f1)}$=1.6.O.6.3.P
Or $\mathrm{Gen2}|_{G_3+G_4(f1)}$=1.6.V.6.3.I
$\mathrm{Gen5}|_{G_1}$=2.8.O.8.1.P
Or $\mathrm{Gen5}|_{G_1}$= 2.8.V.8.1.I

Step 4: The Chromosome represents the expanded elements is as follows:

Chromosome $_{expanded\ elements}$=

$$Gen4|_{-3G_4} \bullet Gen2|_{G_3+G_4(f1)} \bullet Gen3|_{G_3+G_4(f2)} \bullet Gen5|_{G_1} \bullet Gen7|_{G_2}$$

If the first possible representations of all genes are selected, the chromosome will be:

Chromosome $_{expanded\ elements}$=
1.5.O.5.2.I. 1.6.O.6.3.P. 1.7.O.7.4.P. 2.8.O.8.1.P. 3.9.O.9.2.P

Comparing between genes of SO-TA family representations and the resulted chromosome, one can find that Gen4 can be represented by the TA number 3 in Table III with negative terminal is grounded, positive terminal is connected to node 2 and output terminal is connected to node 1. Where, Gen2, Gen3, Gen5 and Gen7 are represented by the TA number 1 in Table III. The negative terminals of the TAs representing the four genes grounded. The positive terminals of the TAs representing the four genes are 3, 4, 1 and 2 respectively. The output terminals of the TAs representing the four genes are 1, 1, 2 and 3 respectively. The final realization of KHN-GA type B with SO-TA is shown in Fig. 4.

As there are six elements in the KHN circuit; five floating elements and one grounded element, and every element can be represented by two genes, so, the number of possible realizations can be calculated as 26 = 64 equivalent SO-TA-realizations. Those realizations are achieved by applying mutation and crossover between genes. For example, by mutating the second gen, the resulted chromosome is as follows:

Chromosome $_{expanded\ elements}$=
1.5.O.5.2.I. 1.6.V.6.3.I. 1.7.O.7.4.P.2.8.O.8.1.P. 3.9.O.9.2. P

After mutation, the nullor and mirror representation of the circuit change and Gen2 can be represented by the TAI- and TAO- in Table III. As TAI- is used in the first realization, so TAO- will be used now. Gen3, Gen5, and Gen7 are represented by the TAI- and Gen4 can be represented by the TAI+. All possible solutions of the circuit are summarized in Table IV utilization the realization of the grounded resistance shown in Fig. 3(a) to realize$\mathrm{Gen1}|_{G_3+G_4(g)}$. The same number can be obtained utilizing the realization of the grounded resistance shown in Fig. 3(b) to realize $\mathrm{Gen1}|_{G_3+G_4(g)}$. The proposed methodology can also be applied to the KHN Type A circuit and get the same number of possible circuits.

The proposed methodology can be applied to KHN-GA circuit type B to get all possible equivalent circuits using CCII family. There are 32 possible solutions for KHN-GA type B and also the same number for type A. It is worth noting that the same number of circuits was obtained in [12], [13] using the NAM expansion method but the advantage of the proposed methodology is its utilization of GA to get all possible circuits programmatically and also, this method can be applied to any other circuit to get its equivalents using all types of active elements.

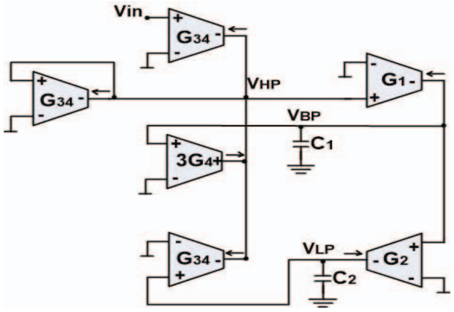


Fig. 4. SISO-TA representation of KHN-GA filter type B

B. Simulation Results

P-Spice simulations were carried out to verify the performance of the equivalent TA-KHN-GA circuits. The TA circuit used for simulation is the one given in [19], [20] with 0.25μ model and supply voltages of ±1.5V. The TA- KHN-GA circuits of Fig. 4 are designed to have f0=1MHz and Q = 10. The input signal is a sinusoidal input voltage source of 1V magnitude. Fig. 5 shows the HP, BP and LP magnitude responses of TA-KHN-GA type B configuration of Fig. 4 compared with the original op amp KHN circuit. It is clear that the TA circuit has a superior performance than the original KHN one. It is clear that the KHN-GA op amp circuit is malfunction at high frequencies whereas the TA-KHN-GA circuit gives a good performance with Q and Δf0 equal 10% and 5% respectively.

IV. CONCLUSIONS

The paper presented a family of KHN-GA equivalent circuits. First a new generation methodology, based on the nullor and mirror representation and the GA, was introduced. This methodology was applied to the KHN circuit, instead of the NAM expansion method, to generate 64 CCII-KHN equivalent circuits for type A and B. It was also applied to generate 128 TA-KHN-GA equivalent circuits for type A and B. it was the first time to utilize the GA to realize CCII-KHN and SO-TA-KHN which help us to get all possible circuits programmatically. The generated circuits have been verified using PSPICE simulation and the simulation results showed that one of generated circuits have better performance compared to the original KHN configurations. It is worth noting that the proposed methodology represents a systematic generation method which can be applied to any other op amp circuit to generate equivalent CCII or TA ones.

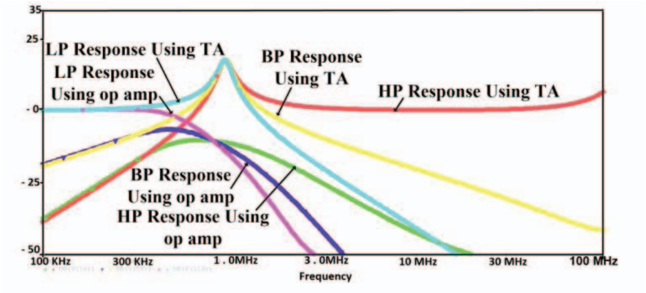


Fig. 5. Magnitude response of TA-KHN type B configuration of Fig. 4 compared with the original op amp KHN circuit.

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TABLE IV. ALL POSSIBLE REALIZATIONS FOR KHN TYPE B USING TA

$Gen2\|_{G_3+G_4(f1)}$	$Gen3\|_{G_3+G_4(f2)}$	$Gen5\|_{G_1}$	$Gen7\|_{G_2}$	$Gen4\|_{-3G_4}$
TAI-	TAI-	TAI-	TAI-	TAI+
TAI-	TAI-	TAI-	TAI-	TAO+
TAO-	TAI-	TAI-	TAI-	TAI+
TAI-	TAO-	TAI-	TAI-	TAI+
TAI-	TAI-	TAO-	TAI-	TAI+
TAI-	TAI-	TAI-	TAO-	TAI+
TAO-	TAI-	TAI-	TAI-	TAO+
TAI-	TAO-	TAI-	TAI-	TAO+
TAI-	TAI-	TAO-	TAI-	TAO+
TAI-	TAI-	TAI-	TAO-	TAO+
TAO-	TAO-	TAI-	TAI-	TAI+
TAO-	TAI-	TAI-	TAO-	TAI+
TAO-	TAI-	TAO-	TAI-	TAI+
TAI-	TAO-	TAO-	TAI-	TAI+
TAI-	TAI-	TAO-	TAO-	TAI+
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TAI-	TAI-	TAO-	TAO-	TAO+
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TAO-	TAI-	TAO-	TAO-	TAO+
TAO-	TAO-	TAI-	TAO-	TAO+
TAI-	TAO-	TAO-	TAO-	TAO+
TAO-	TAO-	TAO-	TAO-	TAI+
TAO-	TAO-	TAO-	TAO-	TAO+