EVOLUTIONARY SYNTHESIS OF CHAOTIC DYNAMICS USING UNIVARIATE MARGINAL DISTRIBUTION ALGORITHM

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Abstract: The paper is focused on the synthesis of the topology and the parameters of analog impedance network with arbitrary input impedance function using the univariate marginal distribution algorithm. As a test problem design of chaotic oscillator circuit is adopted. Impedance network with desired input impedance function is synthesized and employed in the chaotic oscillator. Afterwards, functionality of the oscillator is verified using PSpice simulation.

Keywords: automated analog circuit synthesis, evolutionary algorithm, UMDA, chaos

1 EVOLUTIONARY ANALOG CIRCUIT SYNTHESIS

Variety of approaches as genetic programming [1], genetic algorithms [2], simulated annealing [3], analog genetic encoding [4] or graph grammar [5] have been used for solving of the automated analog circuit design problem. Recently estimation of distribution algorithms (EDA)[6] have shown theirs superior features however there hasn't been paid much attention to employ them in the area of automated analog circuit synthesis. One of the attempts has been published in [7] however this approach has two main drawbacks. There is no possibility of encoding of parallel components and the proposed encoding is problematic for larger analog circuits.

In the paper new encoding method will be presented and using UMDA algorithm for synthesis of chaotic oscillator circuit will be described.

2 UNIVARIATE MARGINAL DISTRIBUTION ALGORITHM

Principal flow chart of Univariate Marginal Distribution Algorithm (UMDA) is presented in Figure 1.

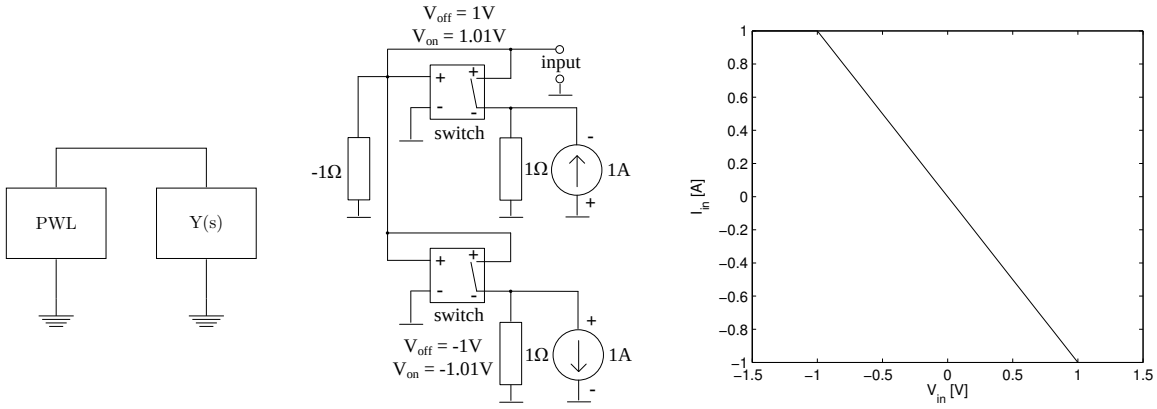
STEP 0: Randomly generate N initial solutions. Set $t = 0$.
STEP 1: According to selection method, select $M \leq N$ candidate solutions.
STEP 2: Calculate marginal frequencies $p_i^s(x_i,t)$ of the selected individuals.
STEP 3: Generate N new solutions according to previously calculated marginal distribution $p(X,t+1) = \prod_{i=1}^{n} p_i^s(x_i,t)$. Set $t = t+1$;
STEP 4: If termination criteria are not met, go to STEP 1.

Figure 1: Flow chart of Univariate Marginal Distribution Algorithm (UMDA).

Univariate Marginal Distribution Algorithm (UMDA) is Estimation of Distribution Algorithm (EDA) in which probabilistic model of promising areas of solution space is built under assumption that there are no dependencies between variables of the solution vector. The basic flow chart is similar to classical genetic algorithm except that recombination phase is replaced by probabilistic modeling. This way some of the drawbacks of genetic algorithms like deceptive functions or building blocks disruption by crossover operation can be overcame.

3 DEFINITION OF THE PROBLEM

For verification of the proposed automated analog circuit synthesis method problem of design of chaotic oscillator circuit was adopted. As can be seen in Figure 2a the oscillator consists of parallel connection of PWL function and admittance network Y(s). Schematic diagram of PSpice realization of PWL function is presented in Figure 2b. On and off resistances of the switches were set to $1\mu\Omega$ and 1TΩ respectively. V/A characteristic of PWL function is presented in Figure 2c.



(a) (b) (c)

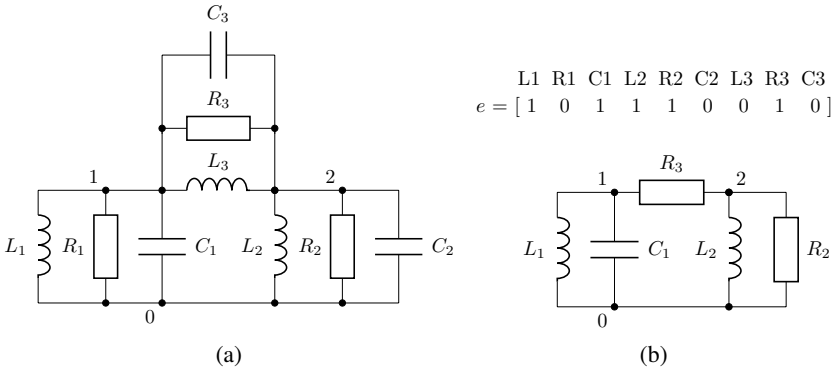
Figure 2: a) Principal schematic of the chaotic oscillator b) PSpice realization of PWL circuit c) Input V/A characteristic of PWL circuit.

Topology and values of the components of Y(s) will be synthesized by means of the proposed method. Desired input impedance of Y(s) is (1). For more details on obtaining (1) please refer to [3].

$$Z_{in} = \frac{0.841 \times 10^{-10} s^2 + 0.816 \times 10^{-5} s - 0.362 \times 10^{-1}}{0.1 \times 10^{-14} s^3 + 0.289 \times 10^{-10} s^2 + 0.598 \times 10^{-5} s - 0.920 \times 10^{-2}} \tag{1}$$

4 ENCODING METHOD

The proposed encoding method is based on the idea of generalized admittance network (GAN). Given n nodes, generalized admittances are connected between all combinations of two nodes. Generalized admittances are then replaced by parallel combination of RLC components. GAN of n nodes includes $p = 3n(n-1)/2$ RLC components. Example of GAN for $n = 3$ nodes is presented in Figure 3a.



(a) (b)

Figure 3: a) Example of GAN for $n = 3$ nodes b) Example of simple analog circuit and its binary encoding vector.

Topology of such network can be encoded using binary vector e of length p where every single bit of e defines including or not including of the corresponding RLC component in the encoded solution. Example of a simple analog circuit and its binary encoding vector are presented in Figure 3b.

As follows from the above number of components of the encoded circuit nc can be calculated as number of "ones" in vector e. Since nc is constrained to user defined value the problem has to be viewed as unitation constraint problem [8]. To enable UMDA to deal with unitation constraint sampling phase of the algorithm was modified. After generating of samples using stochastic universal sampling (SUS) only nc "ones"with the highest probabilities are preserved in every sample. This way every sample encodes circuit with maximally nc components.

For the problem of the synthesis of desired impedance network Y(s) GAN of $n = 10$ nodes was chosen and maximal number of the components nc was set to 15. Schematic diagram of the used encoding vector v is presented in Figure 4.

$$v = [\overbrace{\ b1\ b2\ b3\ \ldots\ b135}^{\text{topology}}]\ [\overbrace{\ b136\ b137\ b138\ \ldots\ b180}^{\text{exponents}}\ ]\ [\overbrace{\ b181\ b182\ b183\ \ldots\ b285}^{\text{mantissas}}\ ]$$

Figure 4: Schematic diagram of the used encoding vector v.

Topology is encoded using bits $b1$ to $b135$. Parameters of the components are represented using exponent and mantissa. Every single exponent is encoded using 3 bits. Every single mantissa is encoded using 7 bits. Since maximal number of components nc is set to 15, encoding vector v encodes parameters for 15 components. Bits $b136$ to $b180$ encode exponents. Bits $b181$ to $b285$ encode mantissas. Gray coding for exponents and mantissas was used.

5 COST FUNCTION

According to (2) cost function is represented as weighted sum of magnitude deviation and phase deviation. Magnitude deviation is calculated as weighted sum of absolute values of differences between desired solution f_{dm} and actual solution f_{am} over m frequency points. Similarly phase deviation is calculated as weighted sum of absolute values of differences between desired solution f_{dp} and actual solution f_{ap} over m frequency points.

$$cost = w_m \sum_{i=1}^{m} w_d(i)|f_{dm}(i) - f_{am}(i)| + w_p \sum_{i=1}^{m} w_d(i)|f_{dp}(i) - f_{ap}(i)| \tag{2}$$

Weights w_m and w_p were set 1 and 0.4 respectively. There were used m = 61 frequency points logarithmically spaced in the range $f_1 = 100$ Hz to $f_2 = 1$ MHz (15 points/decade). Weight w_d was set to 4 in the range 100 Hz to 184.78 Hz, to 1.7 in the range 7.35 kHz to 18.4 kHz, to 1.4 in the range 116.5 kHz to 1 MHz and to 1 for the rest of the frequency points. Magnitude and phase responses were calculated using nodal analysis function implemented in Matlab. Input of the synthesized circuit was fixed to node 1.

6 EXPERIMENTS

UMDA algorithm was implemented in Matlab using EDA toolbox MATEDA 2.0 [9]. Initial population was generated randomly with uniform distribution. Population size was set to 200 individuals. There were performed 20 runs of the algorithm with 500 generations in each run (1e5 cost function evaluations per run). Average run time of a single run of the algorithm was 100 min. The schematic of the best found circuit (cost = 20.74) is presented in Figure 5a. Comparison of it's magnitude and phase characteristics to the desired function (1) are presented in Figure 5b and Figure 5c respectively.

As you can see the accuracy of the solution is very good. After using the synthesized circuit at the place of Y(s) (Figure 2a) the resulting chaotic oscillator was simulated using PSpice. Two plane projections associated with the best found circuit are presented in Figure 5d and Figure 5e.

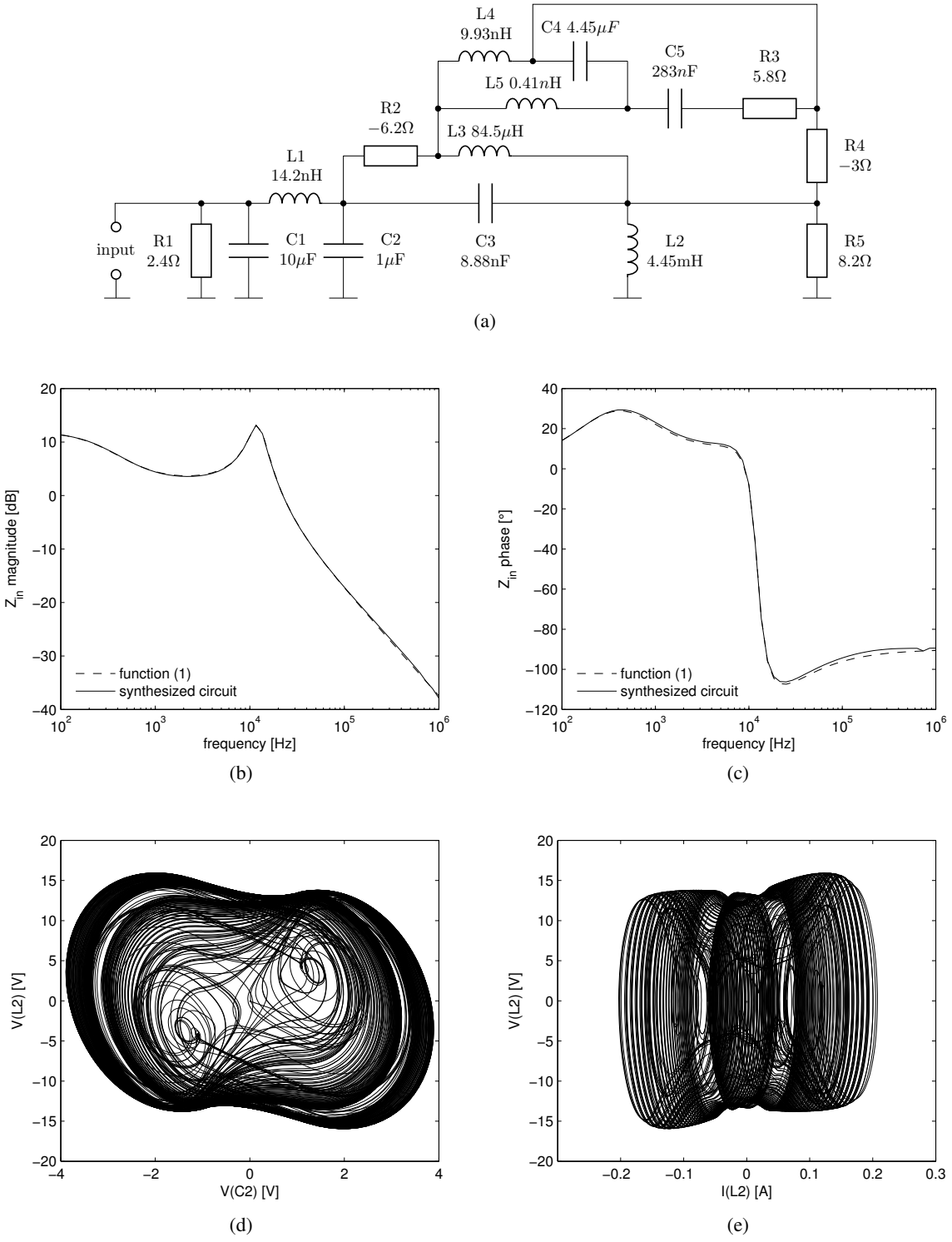


Figure 5: a) Schematic of the best found solution b) comparison of magnitude of the best solution and function (1) c) comparison of phase of the best solution and function (1) d) plane projection V(L2) vs. V(C2) e) plane projection V(L2) vs. I(L2).

7 CONCLUSION

New encoding method and automated analog circuit synthesis method using univariate marginal distribution algorithm (UMDA) were described. There were performed 20 runs of the proposed algorithm and the best found circuit was employed in the chaotic oscillator circuit. Comparison of magnitude and phase characteristics of the synthesized circuit and desired function documents very good accuracy of the synthesized circuit. PSpice simulation in time domain verifies correct function of the oscillator. Since the proposed method is population-based evolutionary algorithm it can be easily extended to enable parallel cost function evaluation. Also multiobjective approach like pareto ranking approach can be applied. Future work will be focused on problems of automated active analog circuits synthesis using estimation of distribution algorithms employing multivariate probabilistic models.

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