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Global similarity tests of physical designs of circuits: A complex network approach

Hu Tan [a,b], Minfang Peng [a,*], Chi K. Tse [c], Fangrong Wu [a]

[a] *College of Electrical and Information Engineering, Hunan University, Changsha, Hunan, China*
[b] *National Engineering Center for Advanced Energy Storage Materials, Changsha, Hunan, China*
[c] *Department of Electronic and Information Engineering, Hong Kong Polytechnic University, Hong Kong, China*

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ABSTRACT

Similarity testing for circuits is an important task in the identification of possible infringement of intellectual property rights. In this paper, we propose a novel procedure for global similarity measurement between circuit topologies (networks) and apply this procedure to the comparison of physical designs of circuits. We first construct networks to describe the way in which circuit elements interact. Then, we evaluate the properties of each node from the resulting networks by calculating the cumulative distribution of characteristic parameters such as degree, clustering coefficient, etc. Based on the maximum vertical distance of each pair of distributions, global similarity testing methods are proposed with consideration of the inhomogeneity of parameter distributions and the scale of the networks. Simulation results show the effectiveness of the strategy in terms of robustness and topological information mining. The methodology described here can be applied to the identification of physical designs of circuits that may contain suspected patent infringement, and it is suitable for a wide range of circuits and systems.

1. Introduction

Intellectual property disputes, such as legal proceedings related to alleged patent infringements, have attracted wide media attention in recent years as they often involve remarkable commercial and public interests. In most cases, allegations are often hard to establish due to the lack of convincing evidence that supports the alleged violations, and some lawsuits could be further complicated by the diversity of the detailed situations of usages and the interpretations of patent coverage. In this paper, we are interested in finding the distinct features in physical designs of electronic circuits in terms of quantitative measures rather than the visual appearance of circuit layouts.

Recent research in network science has aroused a lot of interest across a multitude of application areas [1–4]. There are numerous physical and engineering systems whose structures naturally permit direct application of complex networks as the modeling platform [5–7]. For example, an electronic circuit can be modeled directly as a network which has a structure consisting of nodes connected by edges. The ubiquity of complex networks in science and technology has naturally led to a set of important research problems, such as *similarity testing* which attempts to tell whether two networks are alike, or/and being generated from the same underlying source or mechanism. Numerous methods have been proposed to identify equivalence classes in or between networks [8–11], but the important practical problem of testing global similarity has been rarely considered.

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* Corresponding author.
E-mail address: pengminfang@hnu.edu.cn (M. Peng).

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In this paper, we propose to use a complex network approach to address the problem of similarity measurement, in quantitative terms, between physical designs of electronic circuits. Unlike previous studies in the characterization of complex networks where the average characteristic parameter over all nodes is considered, we evaluate the properties of each node in order to describe the internal differences between two physical designs of a circuit. Based on the properties of each node, we propose a novel approach for global similarity testing. Sections 2 and 3 explain some basic concepts and provide the construction and analysis of the network model. Section 4 presents the global similarity testing strategy and experimental results. Section 5 gives the conclusion.

2. Network construction

A network is usually defined as a collection of *nodes* connected by *links* or *edges* [12]. Small-world structure [13] have been found in networks of electronic circuits ranging from old television circuits to modern digital microchip circuits [5]. To form a network, we need to define what nodes and edges are. For the purpose of constructing a network from the physical design of a circuit, we consider components or modules as nodes, and wires between the nodes as edges. Moreover, some components or modules may have more than one connection. Thus, we assign each edge between two nodes a *weight*, which is the number of actual connections between the two nodes. For simplicity, we represent the physical design of a circuit as a weighted network without specifying edge direction. Then, we may examine the way in which components or modules appear in the physical design for the purpose of constructing a complex network without tedious consideration of signal directions or circuit simulations.

To compare two similar physical designs, two weighted networks G_χ ($\chi = 1, 2$) are defined by sets $N(G_\chi)$ of N_χ nodes, sets $\varepsilon(G_\chi)$ of M_χ edges, and mappings $\omega_\chi : \varepsilon(G_\chi) \mapsto \Re$. Each node is identified by an integer value $i_\chi = 1, 2, \ldots, N_\chi$, and the edges are identified by (i,j) that represents a connection from node $i$to node j, to which a weight $\omega_\chi(i,j)$ is associated. In these weighted and undirected networks, the presence of an edge (i,j) in $\varepsilon(G_\chi)$ means that a connection exists from nodes i to j, and from nodes j to i. The weighted networks can be completely represented in terms of their weight matrix W, so that each element $\omega_\chi(i,j)$ expresses the weight of the connection between nodes i and j. Two nodes i and j are not connected if $\omega_\chi(i,j) = 0$ and are connected with single or multiple connections if $\omega_\chi(i,j) \geqslant 1$.

In the following section we will examine the networks formed from a few distinct types of circuits, including amplifiers [14], filters [7,15] and power supplies [16]. For the purpose of illustration, two typical networks formed using the method described above are shown in Fig. 1, which correspond to half and full bridge designs of universal off-line power supplies. Each node is labeled with its component name, and darkness of coloring of edges indicates relative weights. Differences between half and full-bridge designs are colored yellow in Fig. 1(b).

3. Network analysis

Once the networks are formed, we can compute the basic characteristics. Table 1 shows the number of nodes and edges, total number of edge weights, and network density. The features mentioned above provide basic information for network comparisons. Here, circuits A, B and SV represent a direct coupled amplifier with negative feedback, a direct coupled amplifier with gain feedback, and a state-variable filter respectively. Also, circuits C, D and F represent the half-bridge design, full-bridge design of universal off-line power supplies and a fourth-order low-pass filter, respectively. Obviously, if the number of circuit components differs remarkably, we expect the visual appearance of physical designs or network topologies to differ as well. Therefore, we select the circuit sets with similar amount of components (A, B, SV; C, D, F) for global similarity testing.

Besides, we have calculated the typical characteristic parameters of each node in the network, such as degree, clustering coefficient, average shortest path length, and betweenness centrality. The degree k_i of node i can be found by simply

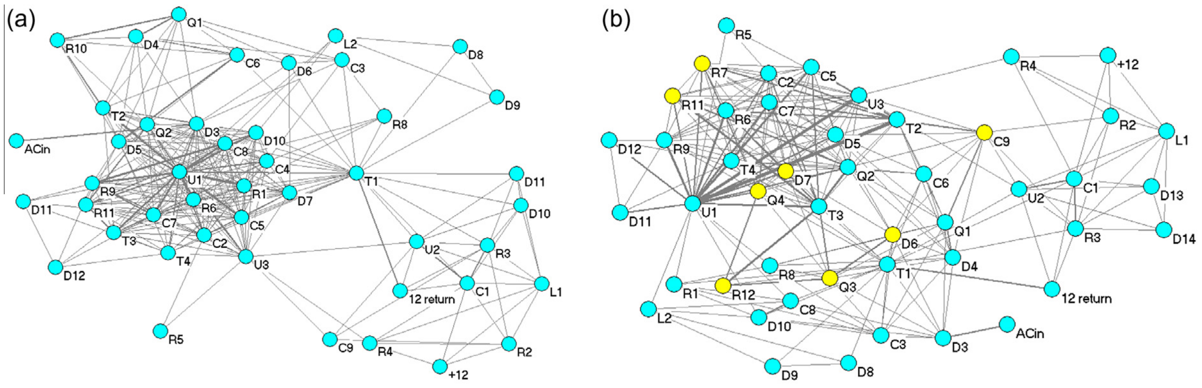

Fig. 1. Networks from universal off-line power supplies: (a) half-bridge design; (b) full-bridge design.