Towards Creative Analog Synthesis: A Symbolic Representation for Exploring Circuit Operation Principles
(Abstract, submitted for oral presentation)

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1. Introduction

Analog electronic circuit design is considered to be by and large an art. This is arguably due to analog design being a less structured and systematic process as compared to digital circuit design. Designers often rely on similarities with previous designs, design experience, on analogies with solutions in other engineering domains, and even on inspiration drawn from biology and anatomy. The main vehicle in creating novel circuit solutions is mainly a designer’s talent to combine basic devices (e.g., transistors, capacitors, etc.) and building blocks into new designs. While the behavior of basic devices and design rules are well understood, the process of combining them in a novel solution is not. Human designers are often unaware of the cognitive process that produced a new design.

In spite of significant results on methods and software tools for synthesis and verification of analog circuits, the design process continuous to be relatively slow, expensive, and error-prone, accessible sometimes only to a small group of experts. Second, educating analog designers is tedious, and can span very long periods. Without a systematic theory on creativity in analog circuit design, it is hard to train students on developing more effectively original solutions. Third, current CAD tools focus on tasks, like transistor sizing and laying out circuits, but still have difficulties in inventing new topologies that resemble closely the kind of circuits that an expert would produce.

An intriguing approach towards a theory on creative design of analog circuits is to develop a computational model that captures the cognitive process of design concept combination and transformation. This model is based on the main cognitive steps of creativity, such as expanding and contracting the active conceptual space, imposing a new context on a solution, similarities, and de-conceptualization. Specifically, our ongoing work focuses on developing a novel analog circuit synthesis methodology that enables creative exploration of an application-specific design space using conceptual models that define the characteristic features of the knowledge domain in analog circuit design. The proposed representation is a symbolic, hierarchical classification scheme that describes the similarities and differences between structurally-different circuits but with similar functionality. This is important to understand the positive and negative impact of a topological structure on the overall circuit performance. The method presented in [1] includes three main steps: identifying the possible classification criteria, ranking the criteria with respect to their capability of finding similar and dissimilar circuit features, and building the hierarchical classification scheme using a separation score based on entropy. In this presentation, we discuss the symbolic representation used to distinguish analog circuits optimized for linearity.

2. Classification of Linear Operational Transconductor Circuits

The procedure in [1] was applied to generate the classification scheme for a set of five linear Operational transconductor circuits (OTAs). The first circuit is a simple differential pair OTA [2]. The second OTA is a source degenerated differential pair that achieves a high linearity by expanding the operation range of the circuit. The third OTA is an adaptive bias transconductor that improves linearity by compensating the non-linear term $A_1v^2$ in the overall differential pair [3]. The correction strategy of cross-coupled differential pairs topology, the fourth OTA [2], considers that the overall processing of a simple differential pair can be expressed as $i_o = A_1(v_1 - v_2) + A_2(v_1 - v_2)$.
The linearity of the difference between the two output currents can be improved by using two independent differential pairs, that share only the input voltages, and by proper selection of $A_1$ and $A_2$ (for each of the two pairs). The fifth circuit is the linear OTA in [4].

Figure 1 shows the classification hierarchy generated for the processing and control paths of the five linear OTAs. The hierarchy highlights that all designs employ current biasing of the differential pair: the associated control path cluster holds only group $G_3$ which contains the five OTAs. For the input voltage processing cluster, the hierarchy indicates that circuits $C_1$, $C_2$, and $C_4$ have a single edge associated with the signal ($H()$ block) while circuits $C_3$ and $C_5$ have additional edges for the same signal, blocks $N()$ and $L()$, respectively.

The hierarchy gives insight about the differences between circuits and their qualitative implications on circuit linearity. For example, the scheme for control paths shows that OTAs $C_2$ and $C_5$ have an additional control voltage ($V_{c2}$) as compared to OTAs $C_1$ and $C_2$. This suggests that in order to meet a given linearity constraint, circuits $C_2$ and $C_5$ offer more flexibility due to the additional control variables. For OTAs $C_2$ and $C_5$, the hierarchy indicates more unmatched nodes for $C_5$ than for $C_2$ on both processing and control paths. This suggests a higher design flexibility for OTA $C_5$ as there is more freedom in meeting the linearity requirements.

References