Chapter 48
Singular Nullor and Mirror Elements for Circuit Design

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Abstract The singular nullor-mirror pathological elements as universal active elements have been found useful in solving circuit analysis and design problems. They find numerous applications in the synthesis, analysis and design of active networks such as modeling different active elements, nodal analysis, circuit transformations, synthesis of active filters, oscillators and other general networks. A summarization of several applications of singular nullor and mirror pathological elements is given in this chapter.

48.1 Introduction

The singular nullor elements (i.e., nullator and norator) are useful in the synthesis and design of active networks. The main reasons for the popularity of nullor elements are their ability to model a variety of different active elements such as transistors (BJT, FET), Op-Amp, Current Conveyor, Four-Terminal Floating Nullor (FTFN), Voltage follower, Current follower, Operational Transconductance Amplifiers (OTA) etc., independently with the particular realization of the active devices. They provide a unified framework for analysis and design of active networks using different active elements. Nullor elements have been accepted within the network theory community as a basic network element and they have been proven to be a very valuable network analysis, synthesis and design tool. Thus, nullors are fast becoming attractive and prominent active elements for analog signal processing/generation. An attempt to point out all research works related to

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"nullors" and their applications in circuit design, covering the period 1961–2000 has been indicated in [1].

Despite the ability of nullors to represent all active devices elements without the use of resistors, they fail to represent some important analog elements. Therefore, two new pathological elements, called current mirror and voltage mirror are defined [2]. The new defined pathological mirror elements are basically used to represent active devices with current or voltage reversing properties. Their usefulness to circuit synthesis and design has been demonstrated in the literature [3–5]. Recently, the mirror elements with grounded reference node have been extended to include the floating mirror elements [6]. With such extensions, a nullator and a norator can be represented in terms of a floating voltage mirror and a floating current mirror, respectively [7]. Moreover, some pathological sections, which ideally represent most popular analog signal processing properties involving differential or multiple single-ended signals, like conversion between differential and single-ended voltages, differential voltage conveying, and inverting current replication, are concisely constructed from floating mirror elements. Since the better flexibility and simpler configuration of modeling active devices using the combination of singular nullor-mirror elements, the pathological representations of many active devices have been proposed in the literature [7–11].

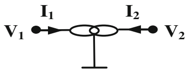
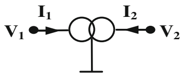
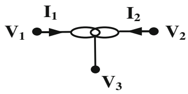
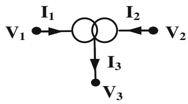
The primary purpose of this chapter is an attempt to summarize several applications of singular nullor-mirror elements for circuit designs proposed in literature. The applications of nullor-mirror elements are classified according to their usage.

48.2 Definitions of Nullor and Mirror Elements

The symbols and definitions of the nullor and mirror elements are shown in Table 48.1. They are singular elements that possess ideal characteristics and are specified on the base of the constraints they impose on their terminal voltage and currents. The nullator and norator own the partial properties of short-circuit and open-circuit. Their symbols and properties are given in Table 48.1a, b, respectively.

The grounded voltage mirror and current mirror shown in Table 48.1c, d are lossless two-port network elements used to represent ideal voltage and current reversing property, respectively. Each of the voltage mirror and current mirror symbols has a reference node, which is set to ground [6]. Although these elements are two-port network elements, they can be used as two terminal elements with the reference node unused [4]. The symbols and definitions of the floating mirror elements are shown in Table 48.1e, f. It can be found that the mirror elements in Table 48.1c–d can be treated as the special cases of the floating mirror elements in Table 48.1e–f, respectively. With the definition of floating mirror elements as Table 48.1, the nullor-mirror models of some active devices with differential voltage input and multiple current output properties can be more concise compared with their pathological representations using mirror elements with grounded reference nodes [11].

Table 48.1 Symbols and definitions of nullor and mirror elements

(a) Nullator		$V_1 = V_2$ $I_1 = I_2 = 0$
(b) Norator		V_1 and V_2 are arbitrary $I_1 = -I_2 =$ arbitrary
(c) Voltage mirror		$V_1 = -V_2$ $I_1 = I_2 = 0$
(d) Current mirror		V_1 and V_2 are arbitrary $I_1 = I_2 =$ arbitrary
(e) Floating voltage mirror		$V_{13} = -V_{23}$ $(V_1 - V_3 = V_3 - V_2)$ $I_1 = I_2 = 0$
(f) Floating current mirror		V_{13} and V_{23} are arbitrary $I_1 = I_2 = I_3/2 =$ arbitrary

48.3 Application of Singular Nullor and Mirror Elements in Circuit Design

There are numerous applications of singular nullor-mirror and their combinations in circuit design. In this section, we try to classify them into various categories as follows.

48.3.1 Modeling Active Devices for Nodal Analysis

Symbolic nodal analysis is a formal technique used to calculate the behavior or a characteristic of a circuit with the independent variable (time or frequency), the dependent variables (voltage and current), and the circuit elements represented by symbols. It is mainly used as a means to gain insights into the behavior of the circuits. The nullor-mirror elements are often used to model all active devices to perform symbolic analysis by applying only nodal analysis. Using the combination of singular nullor mirror elements with grounded reference nodes, the pathological representations of many active devices have been proposed. The various types of operational amplifiers (such as Op-Amp, OTA, OFA, OTRA, COA, etc.) and current conveyors (such as CCIs, CCIIs, CCIIIs, MOCCIs, MOCCIIs, and MOCCIIIs) have been reported in [12]. Also, the behavioral models of fully-differential active devices such as the fully-differential operational floating amplifier, fully-differential floating operational trans-resistance amplifier, fully-differential operational floating conveyor and fully differential current conveyors (e.g. FD Op-Amp, FD OTA, FD OFA, FD OTRA, FD OCA, FD OFC, DDCCs, DCCIIs, DXCCIIs, FDCCIIs, etc.) have been discussed in [13]. Since the above mentioned models use the combination of nullor-grounded mirror elements and resistors, the circuit complexity is therefore increased. Thus, they increase the complexity of the solution method. In order to improve the speed of finding circuit solution, not only the admittance matrix must be as sparse as possible, but also the size of matrix must be kept as low as possible. Such conditions can be achieved if the behavior of active devices can be modeled with simpler nullor-floating mirror elements instead of nullor-grounded mirror elements resistors. The nullator, norator, differential voltage cell, differential voltage conveying cell, current replication cells, BOCCII, DOICCII, FDCCII and DDCC have been represented by nullor- floating mirror elements in [11].

48.3.2 Applying to Circuit Transformations

Network transformations are the techniques to obtain new functional schemes from available circuits. They are systematic methodologies since each transformation technique can be applied to many circuits to obtain the desired functions or characteristics. By interchange the input voltage or current sources and the output norator of a voltage-mode or current-mode circuit, the new system with inverse transfer function can be obtained [14]. Since the difference between a norator and a current mirror is only their current reversing property, the inverse transformation has been extended to apply to circuits with current mirror output [3]. A convenient network transformation method, exploiting inverse and complementary transformations for deriving linear oscillators from biquadratic band-pass filters was reported in [15]. This method in general can be applied to any band-pass filter without the need of specific requirement of circuits. On the other hand, by interchanging nullators with norators, and voltage mirrors with current mirrors in a circuit, the adjoint transformation can be achieved [16]. The adjoint transformations can be applied for deriving current-mode circuit from voltage-mode circuit and vice versa, generation of equivalent oscillator circuits with the same characteristic equation from an original oscillator and other applications [17–19].

48.3.3 Applying to Circuit Synthesis Using NAM Expansion

Recently, a symbolic framework for systematic synthesis of linear active circuit without any detailed prior knowledge of the circuit form was present in [20–24]. This method, named nodal admittance matrix (NAM) expansion, is very useful in generation of specific functional circuits. The matrix expansion process begins by introducing blank rows and columns, representing new internal nodes in the admittance matrix. Then nullor and mirror elements are used to move the resulting admittance matrix elements to their final locations, describing either floating or grounded passive elements properly. Thus, the final nodal admittance matrix (NAM) is obtained including finite elements representing passive circuit elements and unbounded elements, so called infinity-variables [20, 22], representing singular nullor-mirror elements. Two simpler methods for synthesis of voltage-mode and current-mode circuits using NAM expansion was reported in [25, 26]. Based on the above synthesizing method of active network, the generation of several filters, oscillators and gyrators circuits of voltage-mode and current-mode has been proposed [25–32].

48.4 Conclusion

In this chapter, the singular nullor-mirror elements find numerous applications in the synthesis, analysis and design of active networks such as modeling different active elements, symbolic nodal analysis, circuit transformations, synthesis of active filters, oscillators and other general networks. The definition and applications of singular nullor-mirror elements with grounded and floating reference nodes were present. Their practical applications to circuit analysis, synthesis and design in literature have been given.

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