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Analysis of Positive-Negative Frequency Dependent-Independent Active Elements using Variable Gain DVCC-based Generalised Impedance Converter

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ABSTRACT: *Positive and Negative Generalised Impedance Converters with Variable Gain Differential Voltage Current Conveyors are proposed in this paper to synthesise Active components. The variable and frequency-dependent or independent gain is controlled by two external impedances Z1 (floating) and Z2 (grounded), coupled to the VG-DVCC (Variable Gain Differential Voltage Current Conveyor). The Generalised Impedance Converters (GICs) are formed by connecting the grounded impedance Z3 to the X-port of the VG-DVCC. Zin= (Z1*Z3/ Z2) is the input impedance measured at the terminal. Simulation is used to validate the circuit performance and theoretical concept. The synthesis and modelling of various Positive-Negative, Frequency Dependent-Independent Active components are also highlighted in this research. Some examples are positive and negative Active Inductors, FDNR (Frequency Dependent Negative Resistance), FDPR (Frequency Dependent Positive Resistance), Negative Active Capacitors, and Negative Active Resistance.*

Keywords: - Active Inductor, Current Conveyor, Impedance converter, FDNR, FDPR, Negative Capacitor, Negative Resistor

INTRODUCTION

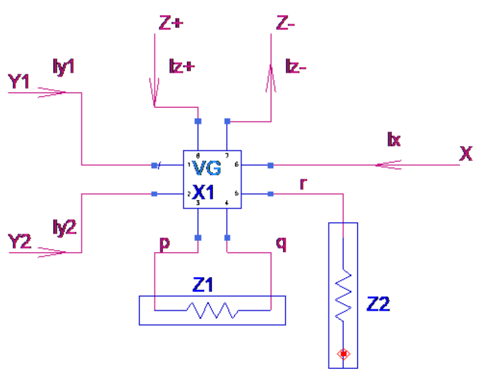
The Active RC network is primarily used to realise Generalised Impedance Converters (GICs). GICs are categorised based on the type of effective impedance provided by the Active RC network. There are two types of GICs: positive GICs and negative GICs. GICs are mostly used to model frequency-dependent components, where the impedance of circuit components changes as the frequency changes. The circuit components include inductors, capacitors, Frequency-Dependent Negative Resistors (FDNRs), and Frequency-Dependent Positive Resistors (FDPRs). GICs also simulate frequency-independent negative components, such as negative resistance and resistance multiplier. Various active building components have been proposed for GICs, including Op-Amps [1, 2], Current Feedback Amplifiers (CFAs) [3, 4], Voltage Differencing Transconductance Amplifiers (VDTAs) [5], Operational Transconductance Amplifiers (OTAs) [6, 7], Voltage Differencing Current Conveyors (VDCCs) [8, 9], and different variations of current conveyors [10-14]. GICs based on voltage-mode active devices have specific restrictions. Firstly, GICs can be categorised as either grounded or floating. Secondly, they can be classified as positive or negative. Thirdly, more than two active devices are typically required for their implementation. Additionally, GICs necessitate using three or more passive components, with odd numbers being common. Grounded GICs can be achieved using single-input single-output active devices, as they have a single live terminal connected to the ground. Conversely, floating GICs require dual-input dual-output active devices since they possess two live terminals. Floating GICs offer greater flexibility as they can be connected anywhere in the circuit, including one grounded end. Consequently, floating GICs can serve as grounded GICs when needed. Based on these findings, it is concluded that Floating Generalised Impedance Converters offer more flexibility and are preferable. Floating GICs require dual and differential voltage input and a dual current output device. Therefore, a configuration like Differential Voltage Current Conveyor (DVCC) is necessary for floating GICs.

I. PROPOSED GIC CONFIGURATIONS

A single active device, VG-DVCC-based floating GICs, is proposed to synthesise positive negative frequency dependent/ independent active components.

A. The Active device: VG-DVCC

The proposed active device, VG-DVCC (Variable-Gain Differential-Voltage-Current-Conveyor), is categorised based on the current at the output port [16].



igure 1: Symbol of VG-DVDOCC

These categories include VG-DVCC+ (positive current output), VG-DVCC- (negative current output), and VG-DVDOCC (dual current output). Among these, VG-DVDOCC is suitable for realising floating GICs. The VG-DVDOCC is a five-port active device with ports Y1, Y2, X, Z-, and Z+. It has three additional terminals, namely p, q, and r, which provide variable gain control. This is achieved by connecting two external components, Z1 between p and q, and a grounded Z2 at r. Figure 1 illustrates the symbolic representation of the VG-DVDOCC. The port characteristics of the VG-DVDOCC are expressed by the following matrix equation (equation-1).

$$\begin{bmatrix} Iz- \\ Iz+ \\ Vx \\ Iy1 \\ Iy2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & +1 & 0 & 0 \\ 0 & 0 & 0 & A & -A \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Vz- \\ Vz+ \\ Ix \\ Vy1 \\ Vy2 \end{bmatrix} \quad ..(1)$$

Where $A = Z_2/Z_1$ is a variable gain.

In current conveyors, the current Ix plays a significant role. Ix can be introduced externally or generated by connecting a grounded impedance Z3 at the X-terminal, as depicted in Figure 2. We can observe the relationships among the variables to simplify the circuit analysis shown in Figure 2 and reduce redundant dependent and independent variables in the matrix (1). From equation-1, it becomes evident that the dependent variables IY1 and IY2 are zero. Additionally, Vx depends on VY1 and VY2, while Iz+ and Iz- rely on IX. None of the variables are dependent on VZ+ and VZ-. Considering the circuit connection, we can express the relationship between IX and Vx as IX = -Vx/Z3. This equation shows that the current IX is directly proportional to the negative of Vx and inversely proportional to the impedance Z3 connected to the X-terminal. By manipulating these relationships, we can simplify the analysis and reduce the number of variables involved in the matrix equation.

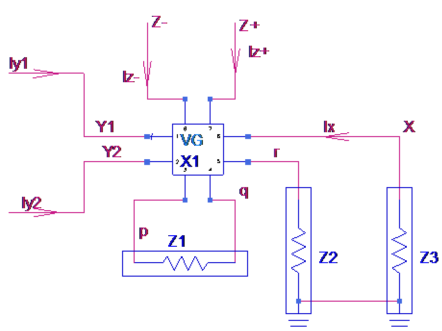


Fig 2: The VG-DVDOCC with Z_3

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From these observations, the characteristic equation (1) of VG-DVCC is reduced into matrix equation (2).

$$\begin{bmatrix} Iz- \\ Iz+ \end{bmatrix} = \frac{1}{ZT} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} Vy1 \\ Vy2 \end{bmatrix} \quad (2)$$

$$\text{Where } Z_T = \frac{Z1*Z3}{Z2} \quad (3)$$

B. Floating GICs

The simple two-port network model of floating GIC is shown in Fig 3.

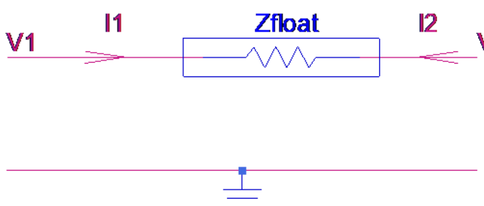

Figure 3: Floating GIC Model

The two-port characteristic of floating GIC is expressed by the admittance matrix as given in equation (4).

$$\begin{bmatrix} I1 \\ I2 \end{bmatrix} = \frac{1}{Zfloat} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} V1 \\ V2 \end{bmatrix} \quad (4)$$

Positive Floating GIC: a positive Generalised Impedance converter is obtained by connecting I_{Z-} to Y_1 and I_{Z+} to Y_2, as shown in Fig 4.

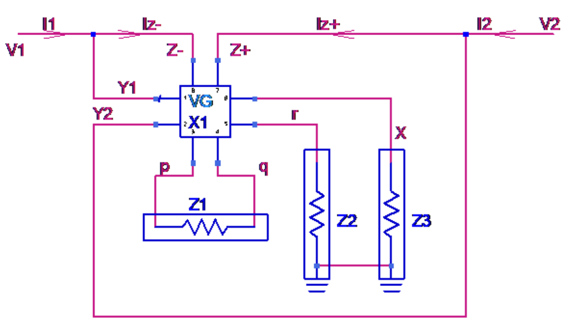

Figure 4: Positive Floating GIC

The Positive floating GIC circuit Fig. 4 is analogous to the simple model of floating GIC of Fig 2; with analogy $I_1 = I_{Z-}$, $I_2 = I_{Z+}$, $V_1 = V_{Y1}$ and $V_2 = V_{Y2}$. The admittance matrix equation (4) for Positive floating GIC becomes as given below.

$$\begin{bmatrix} Iz- \\ Iz+ \end{bmatrix} = \frac{1}{Zfloat} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} Vy1 \\ Vy2 \end{bmatrix} \quad (5)$$

From equations (2) and (5), we get Z_{float} positive, and it is denoted by $Z_{float(+)}$.

$$Z_{Float(+)} = Z_T = \frac{Z1*Z3}{Z2} \quad (6)$$

Negative Floating GIC is obtained by connecting I_{Z+} to Y_1 and I_{Z-} to Y_2, as shown in Fig 5.

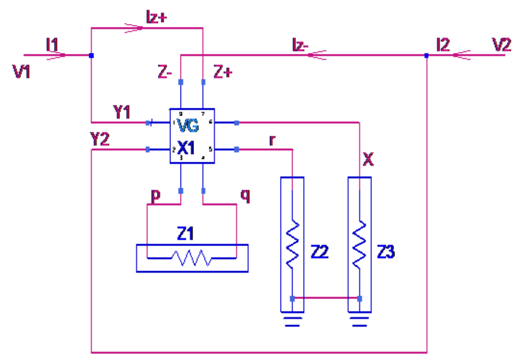

Figure 5: Negative Floating GIC

Here analogy is $I_1 = I_{Z+}$, $I_2 = I_{Z-}$, $V_1 = V_{Y1}$ and $V_2 = V_{Y2}$. The resultant admittance matrix equation is as given below

$$\begin{bmatrix} Iz+ \\ Iz- \end{bmatrix} = \frac{1}{Zfloat} \begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} Vy1 \\ Vy2 \end{bmatrix} \;\ldots.\; (7)$$

$$\begin{bmatrix} Iz+ \\ Iz- \end{bmatrix} = \frac{-1}{Zfloat} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} Vy1 \\ Vy2 \end{bmatrix} \;\ldots.\; (8)$$

Here, the constant multiplier to the admittance matrix is negative, which indicates the impedance offered is negative and denoted by $Z_{float(-)}$.

$$Z_{float(-)} = -\,Z_T = -\,\frac{Z1*Z3}{Z2} \quad \ldots\; (9)$$

II. SYNTHESIS OF ACTIVE COMPONENTS

Resistance Multiplier, Capacitance Multiplier, Positive Inductance and FDNR are synthesised

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using Positive floating GIC, whereas Negative Resistance, Negative Capacitance, Negative Inductance and FDPR are synthesised using Negative floating GIC. Table I details the design requirements for synthesising active elements and their relational equation with passive components.

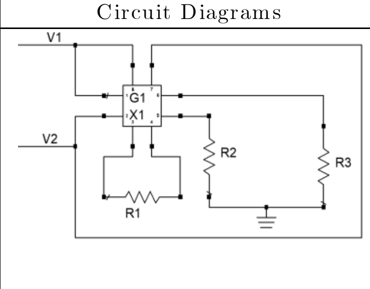
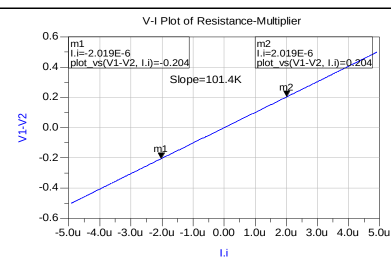
III. SIMULATIONS AND RESULT ANALYSIS

For validation of proposed GICs and Active Components, the simulations of all eight active components were carried out on EDA tools. The actual circuit of the active components, the values of passive components used for their simulation purpose, simulation result characteristics and analytical comment on the performance are tabled in Table -2. From the simulation results, it is observed that (1) all active components are synthesised using single VG-DVCC; (2) all active components are linear; (3) the worst-case inaccuracy of them is always less than ±10%; in frequency response, there is a phase lag/lead up-to 10^0 than the expected in their V-I relations. Most of these active components are frequency dependent; the performance is better for a particular band of frequencies. Also, the capacitor selection depends on the application's operating frequency.

Table 1: Comparative design requirements for synthesis of active components

Active Components	GIC Class	Z_1	Z_2	Z_3	Relational Equation
Resistance Multiplier	Positive	R_1	R_2	R_3	$R_M = \frac{R1*R3}{R2}$
Negative Resistance	Negative	R_1	R_2	R_3	$R_N = -\frac{R1*R3}{R2}$
Capacitance Multiplier	Positive	R_1	R_2	C_3	$C_M = \frac{R1}{R2}*C_3$
Negative Capacitance	Negative	R_1	R_2	C_3	$C_N = -\frac{R1}{R2}*C_3$
Positive Inductance	Positive	R_1	C_2	R_3	$L_P = R_1*C_2*R_3$
Negative Inductance	Negative	R_1	C_2	R_3	$L_N = -R_1*C_2*R_3$
FDNR	Positive	C_1	R_2	C_3	$D_N = \frac{-1}{\omega^{2C1R2C3}}$
FDPR	Negative	C_1	R_2	C_3	$D_P = \frac{1}{\omega^{2C1R2C3}}$

Table 2: Circuit Diagrams and Simulation Results of Active Components

Active Elements	Circuit Diagrams	Simulation Characteristics
Resistance Multiplier Passive components R_1=250KΩ, R_2=500KΩ R_3=200KΩ Designed Value R_M= 100KΩ Simulation Result R_M= 101.4KΩ Inaccuracy = ±1.4%		

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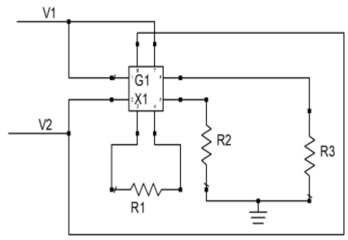
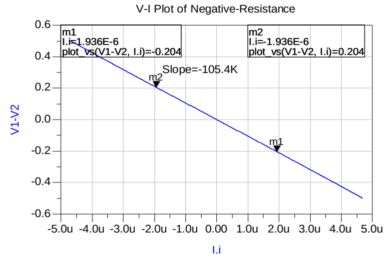
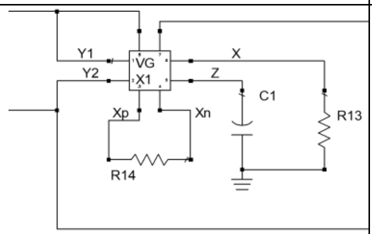
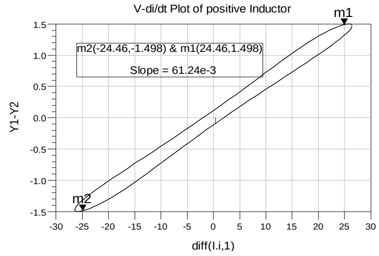
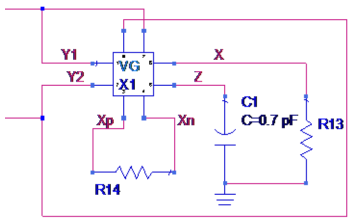
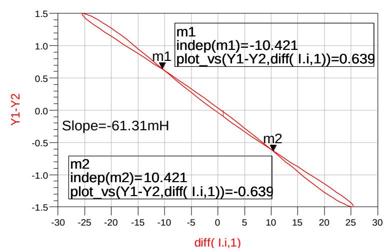
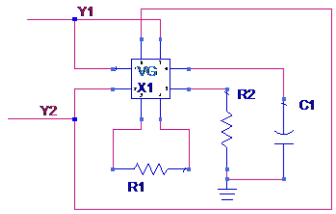
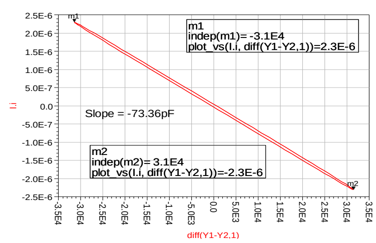
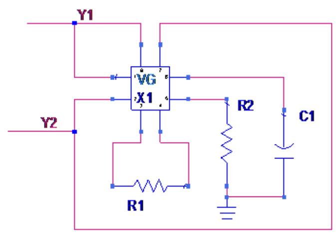
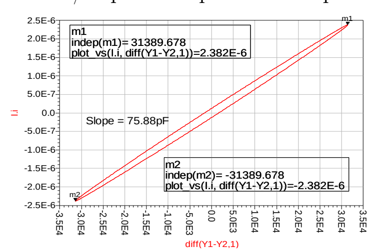
Negative Resistance Passive components R_1=250KΩ, R_2=500KΩ R_3=200KΩ Designed Value R_N= -100KΩ Simulation Result R_N= -105.4KΩ Inaccuracy = ±5.4%		
Positive Inductor Passive components R_1=300KΩ, C_2=0.7uF R_3=300KΩ Designed Value L_P= 63mH Simulation Result L_P= 61.24mH Inaccuracy = ±2.8%	V=Ldi/dt & L= Slope of V - di/dt plot	
Negative Inductor Passive components R_1=300KΩ, C_2=0.7uF R_3=300KΩ Designed Value L_P= 63mH Simulation Result L_P = -61.31mH Inaccuracy = ±2.7%	V=Ldi/dt & L= Slope of V- di/dt plot	V – di/dt plot of Negative Inductor
Negative Capacitor Passive components R_1=300KΩ, R_2=300KΩ C_3=70pF Designed Value C_N= -70pF Simulation Result C_N = -73.36pF Inaccuracy = ±4.8%	I =Cdv/dt & C= Slope of I - dv/dt plot	I – dv/dt plot of Negative capacitor
Capacitor Multiplier Passive components R_1=300KΩ, R_2=300KΩ C_3=70pF Designed Value C_N= 70pF Simulation Result C_N = 75.88pF Inaccuracy = ±8.4%	I = Cdv/dt & C= Slope of I–dv/dt plot	I – dv/dt plot of capacitor Multiplier

<table>
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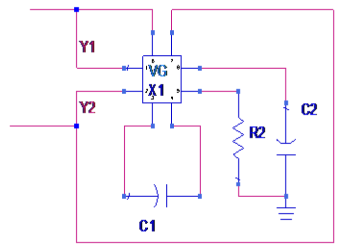
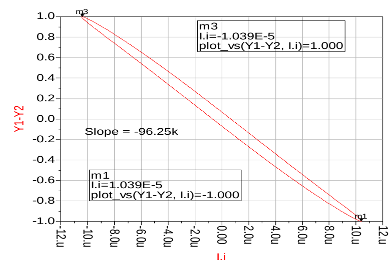
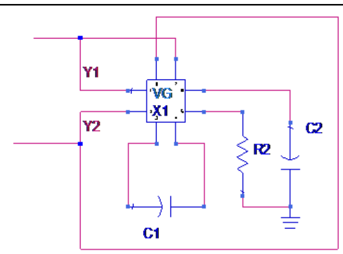
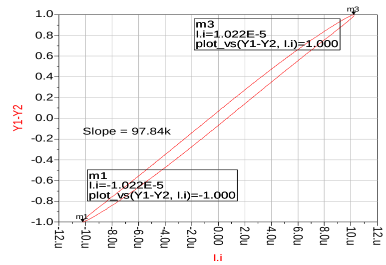
<td>FDNR
Passive components
C_1=0.1nF,
R_2=300KΩ
C_3=0.08nF
F=10KHz
Designed Value
D_N= -105.56KΩ
Simulation Result
D_N = -96.25KΩ

Inaccuracy = ±8.8%</td>
<td>

V= D*I & D = slope of V – I plot</td>
<td>V-I plot of FDNR

</td>
</tr>
<tr>
<td>FDPR
Passive components
C_1=0.1nF,
R_2=300KΩ
C_3=0.08nF
F=10KHz
Designed Value
D_P= 105.56 KΩ
Simulation Result
D_P = 97.84KΩ

Inaccuracy = ±7.3%</td>
<td>

D = slope of V – I plot</td>
<td>V-I plot of FDPR

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IV. CONCLUSION AND FUTURE SCOPE

The VG-DVCC is a multifunctional active device. A single VG-DVDOCC is enough to implement floating-type Positive and Negative Impedance Converters. Positive GIC synthesises Resistance Multiplier, Capacitance Multiplier, Positive Inductance, and FDNR, whereas Negative GIC synthesises Negative Resistance, Negative Capacitance, Negative Inductance, and FDPR. The simulation results reveal that (1) all synthesised active components are linear; (2) inaccuracy is less than 10%; and (3) phase lag/lead is up to 100 times greater than planned. Active components tuned for a specific frequency employing positive or negative GIC offer higher performance characteristics over a specific frequency band because most are frequency-dependent. Also, choosing capacitor(s) is crucial when designing them. Design, simulation, analysis and implementation of various applications such as magnetic interference-free high-order filters, LC oscillators, Relaxation oscillators and chaotic dynamics; those can be easily developed using proposed Active Components.

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