Floating- inductance Simulator using Multi-output Current Controlled Conveyors

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Abstract — **In this paper, a generalized active immittance simulator circuit using three multi-output current controlled conveyors (MCCCIIs) and three passive components is presented. Depending on the passive elements selection, the proposed circuit can realize synthetic floating inductor and floating frequency-dependent negative resistor (FDNR). The unique features of this circuit offer the following advantages: (i) No requirement on component matching for the desired schema; (ii) Independent control of immittance value facilitated through two resistors. For the application, the inductor in the LCR passive filter circuits can be replaced by the proposed floating inductance simulator. Thus, the advantages of these new active RC filters without an inductor can include low component sensitivities and utilize the extensive capability of the primary LCR filter design. In order to show the performance of the proposed immittance simulator circuit, a second-order voltage-mode RLC passive bandpass filter is experimentally demonstrated. The ideal simulated and experimental results of the filter confirming the theory are included.**

Key words: multi-output current controlled conveyor, inductor simulator, analog circuit design, active filter

1. Introduction

Active filters are widely used in signal processing. Many circuits employing the second-generation current conveyors (CCIIs) or the four-terminal active current conveyors as active elements for current-mode filters, voltage-mode filters, sinusoidal oscillators and immittance function simulators have been presented earlier [1]~[19]. The multi-output current controlled conveyor (MCCCII) is also a versatile building block, because it can extend operating large signal bandwidth, great linearity, wide dynamic range, high input impedance and arithmetic operation capability. Recently, the MCCCIIs have been applied in the areas of simulation inductance design, filters, and cancellation of parasitic elements [15]~[23]. For example: Jiraseree-amornkun and Surakampontorn employed some MCCCIIs and some passive elements to synthesize the simulation of floating inductance and filters. Jiraseree-amornkun and Surakampontorn proposed a Butterworth lowpass filter, an elliptic lowpass filter and a Chebyshev bandpass filter again [15] ~ [17]. Zhijun used five MCCCIIs and two grounded capacitors to realize low-pass, high-pass, band-pass filter functions from the same topology simultaneously in 2009 [18]. Yin proposed a current-mode filter circuit which can realize either notch or all-pass or lowpass or highpass or bandpass filter using four MCCCIIs as active elements together with some passive components in 2011 [19]. Yin employed two MCCCIIs and some passive elements to synthesize current-mode notch, highpass, allpass, bandpass and lowpass filters in 2012 [20]. The required number of the active components for the above filters is quite large. Minimizing the number of the active component has the advantages of low cost and power dissipation. Yin and Liu used one MCCCII and some passive elements to construct the voltage-mode and current-mode configuration filter circuits, which can realize bandpass, lowpass, highpass, notch and allpass filters [21]~ [23]. In the area of active filter design, inductor simulation has attracted considerable interest, because the advantage of designing active filters by simulating the inductor of a passive LCR realization of the filter include low component sensitivities and the ability to utilize the extensive knowledge of LCR filter design. The grounded inductor is also frequently required for the design of analogue IC building blocks. For this reasons, it is attractive to use MCCCII-based circuits for simulating grounded-inductor. In 2016, a grounded inductance simulator using two MCCCIIs, a grounded capacitor and two grounded resistors was constructed by Yin and Liu [24]. However, the MCCCII-based floating inductance-simulation circuit has never been presented apparently. Because the floating inductor of the RLC passive filters cannot be transferred to RC active filters by the proposed grounded inductor simulator. For this reason, the simulated floating inductor need be constructed to solve the mentioned problem. In this paper, a new circuit configuration for the simulation of floating inductance and FDNR using three MCCCIIs and three passive components is proposed. The proposed floating immittance simulator circuit has no passive component matching condition imposed. As an application sample, the simulated floating inductor is used to replace the floating inductor of the LCR passive filters. Moreover, the new RC active filters can enjoy low component sensitivities and extensive knowledge of LCR filter design and benefit from the LCR passive filters. Finally, a RLC passive filter using the proposed simulated inductor is given to confirm the afore mentioned theoretical analysis.

2. CIRCUIT DESCRIPTION

The circuit symbol for a MCCCII is shown in Fig.1. The port relations of a MCCCII can be characterized as $V_x= V_y+ I_xR_x$, $I_y=0$, $I_{Z+}=I_x$ and $I_{Z-}=-I_x$. The '+' and '-' signs of the current i_z denote the non-inverting and inverting, respectively.

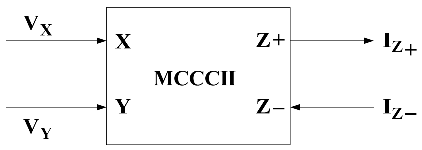


Fig.1. A MCCCII symbol.

The active immittance simulator circuit is shown in Fig.2, where Z_1~Z_3 are impedances. By routine analysis, one get, for the circuit of Fig.2, the input impedance of the active immittance simulator equation is given by

$$Z_{in}=\frac{Z_1Z_3}{Z_2} \quad \text{-------------------------- (1)}$$

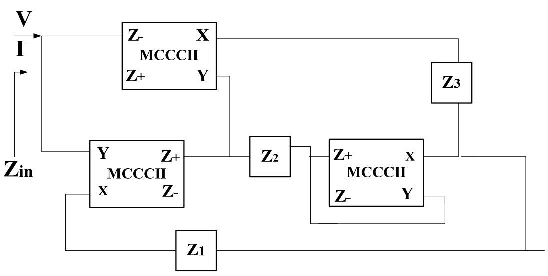


Fig.2 The proposed floating impedance simulator.

where Z_1, Z_2 and Z_3 are the impedances. By choosing suitable passive components from the impedances Z_1, Z_2 and Z_3 in equation (1), the floating inductors and floating frequency dependent negative resistors can be obtained as follows:

(1) If $Z_1=R_1$, $Z_3=R_3$, and $Z_2=(1/sC_2)$, are taken, the impedance of the floating inductor is obtained as

$$Z_{in} = sL_{eq} = sC_2R_1R_3 \quad \text{-------------------------------- (2)}$$

where $L_{eq}= C_2R_1R_3$. The sensitivities of the active inductance are

$$S_{C_2}^{L_{eq}} = S_{R_1}^{L_{eq}} = S_{R_3}^{L_{eq}} = 1$$

From the above equation (2), properly selecting values of the resistors and capacitors, both large and small values of inductance and capacitance can be obtained. Thus, the floating inductance simulator is constructed and its values are independently tunable through the three passive elements in the circuit of Fig. 3.

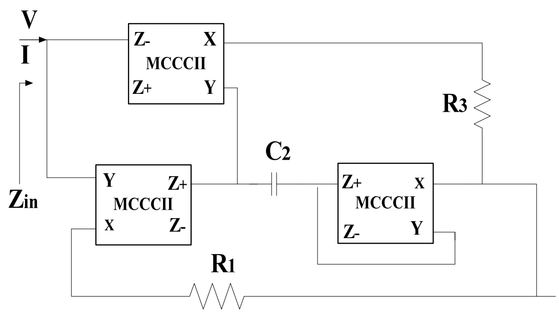


Fig.3. The proposed floating inductance simulator.

(2) If $Z_3 = (1/sC_3)$, $Z_1 = (1/sC_1)$, and $Z_2=R_2$, are taken, the floating FDNR is given by

$$Z_{in}=\frac{1}{sD_{eq}}=\frac{1}{s^2C_1C_3R_2} \quad \text{------------------------ (3)}$$

where $D_{eq}= C_3C_1R_2$. The sensitivities of the active FDNR are

$$S_{C_1}^{D_{eq}} = S_{C_3}^{D_{eq}} = S_{R_2}^{D_{eq}} = 1$$

Similarly, the floating FDNR simulator can be obtained and its values are independently tunable through the three passive elements. From (2), it can be seen that by properly selecting values of the resistors R_1, R_3 and the capacitor C_2, very large as well as very small values of inductance can be easily obtained.
Clearly, the floating inductance simulator is constructed.

3. SIMULATION AND EXPERIMENTAL RESULTS

The AD844, as integrated circuit, is now commercially available. The MCCCII is implemented by three ICAD844s, three IC op-amps and five resistors. The theoretical characteristic of the FDNR, described in Fig.2, is given for $Z_1=Z_3=1\ \mu F$ and $Z_2=10k\Omega$. The Matlab analysis is proven to be effective when the optimum curve of the FDNR circuit is applied shown in Fig.4. It is observed from equation (3) and figure 4 that the impedance of the FDNR decreases with increasing frequency.

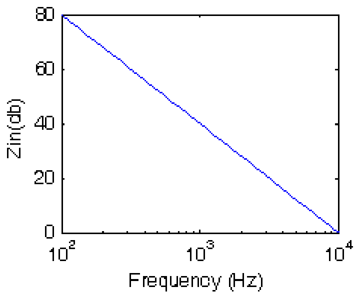


Fig.4: The ideal curve of the FDNR for $C_1= C_3=1\ \mu F$ and $R_2=10k\Omega$.

If the proposed simulation floating-inductor was experimentally tested using $R_1=R_3=1K\Omega$, $C_2=1\ \mu F$ and IC AD844s, the proposed circuit shown in Fig.3 can be equivalent to an inductor with $L_{eq}=1H$. Then, this simulation floating-inductor can be used in the realization of the series RLC passive bandpass filter shown in Fig.5 and the transfer function has a biquadratic bandpass characteristic with

$$\frac{v_{out}}{v_{in}} = \frac{(\frac{R}{L_{eq}})s}{s^2 + s(\frac{R}{L_{eq}}) + \frac{1}{L_{eq}C}} \text{ ------------------------ (4)}$$

the central frequency: $\omega_o = (\frac{1}{L_{eq}C})^{1/2}$ ----------- (5)

the quality factor: $\vartheta = R(\frac{L_{eq}}{C})^{1/2}$ ------------------- (6)

The sensitivity of ω_o and ϑ according to passive components are:

$$S_{C_2}^{\omega_o} = S_{R_1}^{\omega_o} = S_{R_3}^{\omega_o} = S_{C}^{\omega_o} = S_{C}^{\vartheta_o} = -\frac{1}{2},$$

$$S_{R_1}^{\vartheta_o} = S_{R_3}^{\vartheta_o} = S_{C_2}^{\vartheta_o} = \frac{1}{2},$$

$$S_{R}^{\vartheta_o} = 1$$

all of which are small.

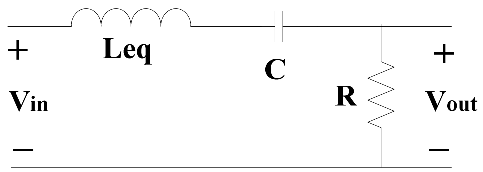


Fig.5 The prototype passive series RLC bandpass filter.

In Fig.6, a second-order bandpass filter was constructed with $R = 1K\Omega$, $C = 1\ \mu F$ and $L_{eq}=1H$. The Matlab has simulated the ideal curves of the bandpass filter. The measured values were found using a Hewlett Packard network/spectrum analyzer 4195A. The resonance frequency was monitored and measured and the corresponding inductance value was calculated and compared with the theoretical value calculated using equation (2). The experimental results for the gain and phase responses shown in Fig.7 (a) (b) demonstrate similarity between theoretical calculation and actual measurement. There is a high correlation between the theoretical analyses and the measured results with only minor errors due to the use of passive elements.

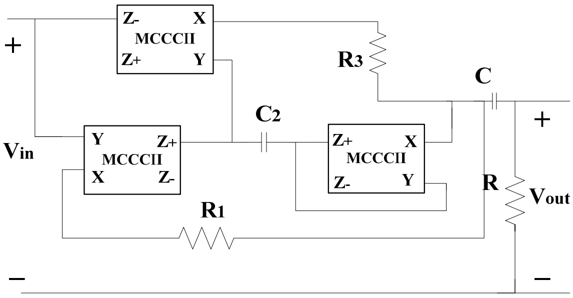
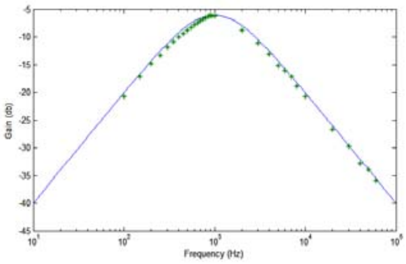
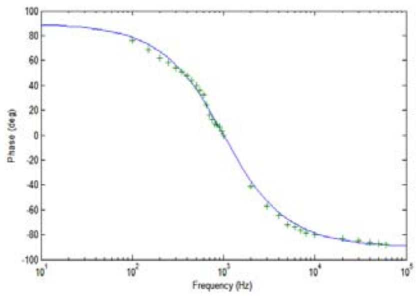


Fig.6 Bandpass filter circuit used to test the inductor realized using circuit of Fig. 4.



(a).The gain response curve of the banspass filter using simulated inductor.



(b). The phase response curve of the banspass filter using simulated inductor.

Fig.7 (a): The gain response curve of the banspass filter using simulated inductor.
(b): The phase response curve of the banspass filter using simulated inductor.
*: Experimental result for banspass gain
+: Experimental result for bandpass phase
—: Ideal curve

4. CONCLUSION

The concept of the floating inductor and FDNR using three MCCCIIs and three passive elements is proposed. The inductance value of the proposed circuit can be independently tunable through the three elements - R_1, R_3 and C_2, and it does not require matching of any passive component. The advantages of RC active filter when constructing filter transferred by the proposed circuit includes low component sensitivities and the ability to utilize the extensive capability of LCR filter design. Finally, the experimental results on floating inductor utilizing a LCR bandpass passive filter confirmed the theoretical analysis.

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