Catalog of Realizations for DXCCII using Commercially Available ICs and Applications

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Abstract. *This paper presents fifteen distinct practical realizations for dual-X second generation current conveyor (DXCCII) using commercially available integrated circuits. Detailed comparisons and results are presented to verify the utility of proposed realizations. The catalog of proposed realizations is a first attempt and is expected to be useful for testing newly developed circuits based on dual-X second generation current conveyor. Each of the first fourteen proposed realizations uses four ICs. One three IC based implementation is further given making the total count fifteen. Some additional features are also explored which further enhance the versatility of DXCCII. The paper further presents a novel and compact quadrature oscillator to verify the applicability of the proposed realizations. Single resistance control of the frequency of oscillation is also demonstrated by employing the new gain-variable DXCCII. Experimental results are also included along with simulation results to validate the proposed theory and its practical significance.*

Keywords

Current Conveyors, DXCCII, Analog Signal Processing, AD844, Quadrature Oscillator, Active-RC.

1. Introduction

The field of analog signal processing has attained new dimensions with the wide popularity of current-mode active elements and high performance functions being realized from these elements [1]-[4]. The ever increasing demands for higher performance systems have led to the development of active elements suited for design of analog and more recently even digital circuits and systems [1]-[5]. The proposals in form of new CMOS implementations have ensured easy verification of newly developed circuits for diverse electronic functions. However, the fabrication industry has been reluctant in producing/introducing new chips as and when they are actually proposed by circuit designers and researchers in a given technology, due to either investment cost or acceptability reasons. The non-availability of ICs for such active elements is often a hindrance to the actual testing or adoption of newly developed circuit designs. In these cases, the only way out is to realize such active elements using commercially available ICs, even if the realization is not cost effective and at times even cumbersome. Such attempts have been made in the literature with effective results [6]-[11]. Of special interest is the work which presents the realization of several active building blocks using diamond transistors [7]. However, it may be noted that AD844 has also become a standard commercial IC for realizing various types of current conveyor based networks.

One such active element which has been recently popularized by analog circuit designers is dual-X second generation current conveyor (DXCCII) [5], [12]-[16]. This paper presents a variety of possible realizations for DXCCII using commercially available chips. In all, fifteen distinct realizations are proposed and compared. The same have been verified through computer simulations. Some new feature enhancements have further been explored based on one of the proposed realizations of DXCCII. These further add to the versatility of DXCCII. These new enhancements include a DXCCII with buffered output and a gain-variable DXCCII. The DXCCII with buffered outputs is used to realize a quadrature oscillator. Furthermore, the proposed quadrature oscillator is also made tunable by employing the gain-variable DXCCII, while retaining the buffered output capability. Experimental results for the proposed quadrature oscillator are also given.

The remainder of this paper is arranged as follows: Section 2 contains the proposed realizations of DXCCII using commercially available chips. Section 3 deals with the verification of the proposed realizations. PSPICE simulation results are presented to ascertain validity of the various implementations. Detailed comparison of the characteristics of the different implementations also appears in this section. Section 4 presents a few feature enhancements for one of the proposed implementations of DXCCII. An example of a new voltage-mode quadrature oscillator employing a single DXCCII is presented in Section 5. Results of breadboard implementation of the oscillator using one of the proposed DXCCII implementtations are also included. Further, single resistance control of the frequency of oscillation is also demonstrated. Concluding remarks are presented in Section 6.

2. Proposed Realizations

A DXCCII, shown in Fig. 1, is characterized by the following ideal terminal relationship:

$$\begin{bmatrix} I_Y \\ V_{XP} \\ V_{XN} \\ I_{ZP} \\ I_{ZN} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_Y \\ I_{XP} \\ I_{XN} \end{bmatrix}. \quad (1)$$

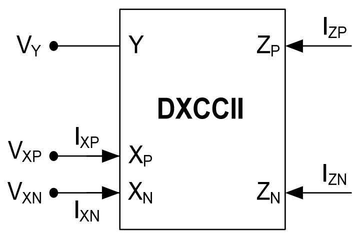

Fig. 1. DXCCII symbolic representation.

The DXCCII is a combination of conventional second generation current conveyor and inverting second generation current conveyor (ICCII) [1], [2]. It is more versatile as it combines the features of both CCII and ICCII. DXCCII implementation in CMOS technology as given in [12] can be easily derived from an earlier known active element named FDCCII [16]. In spite of the availability of CMOS DXCCII, there has been a demand by knowledge contributors for possible realizations of this active building block using commercially available ICs. Such a demand is targeted not only to provide possible experimental support for various applications of DXCCII, but also to motivate new researchers to test their ideas by actual breadboard implementation. The motivation of this paper is to propose various possible realizations for DX-CCII using available ICs. The proposed realizations are given in Figs. 2, 3 and 4. It may be noted that fifteen circuits are given for the purpose. The ICs used in the first seven realizations are AD-844 only (Fig. 2) whereas the next seven realizations use opamp along with AD-844s (Fig. 3). Finally, a DXCCII realization is given which utilizes a differential output opamp and two AD844s (Fig. 4). As far as the voltage opamp is concerned, the same needs no introduction, as it is well known to readers. The ideal terminal characteristics for an AD-844 are given by the following port relations [17]

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \\ V_W \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \\ I_W \end{bmatrix}. \quad (2)$$

It is a well-known fact that AD-844 is equivalent to a second generation current conveyor with additional feature of buffered voltage output and has been a natural choice for realizing current conveyor and its assorted offshoots. The technical literature has witnessed such realization for purpose of either disseminating knowledge or providing support to the research developments [6]-[11]. For instance, one recent work demonstrated the workability of a complicated active functional block (CCCCTA) operating in mixed-mode using commercially available components [8]. The proposed work in this paper further enriches the contemporary knowledge in the field by encompassing DXCCII with a variety of distinct possible realizations using commercially available components.

Of the fifteen proposed realizations for DXCCII, a brief description and comparison of these is in order. A feature common to the first fourteen circuits is the use of four ICs. In such realizations, it is preferred that the only one type of ICs are employed, implying that AD-844 only based realizations (Fig. 2) are better options than the ones utilizing opamps along with AD844s (Fig. 3). It is further desirable from performance viewpoint, since the feature of AD-844 in terms of bandwidth and slew rate are unmatchable with even the highest speed available voltage-mode opamp. Therefore the implementation of DX-CCII utilizing both AD-844 and opamp would be marred by the limitation of opamp. However, the ones utilizing only AD-844 guarantee good performance and accurate realization of the DX-CCII. It may be noted that the circuit of Fig. 2(a) uses three resistors, whereas rest of other thirteen circuits use only two resistors in each case. The circuits of Fig. 2 (b, e) benefit from using only grounded resistors unlike rest of the realizations. Next, the Y port input impedance would be higher for Fig. 2 (a, e, g) and Fig. 3 (e, f) as compared to the other realizations, because of another connection at that node with either another opamp or AD-844. The output impedance at Z ports (Z_P and Z_N) would be the same for all topologies, it being the Z terminal of AD-844 in each case. Similarly, the X-port impedance (especially at X_P) would be the same for Fig. 2 (a, b, c, d, f) and Fig. 3 (a, b, c, g) but would be affected by another connection at X_P node for Fig. 2 (e, g) and Fig. 3 (d, e). As far as X_N is concerned, the impedance level in all topologies would be identical. As far as the frequency performance is concerned, as already mentioned, the AD-844 only realizations would outperform the ones using voltage opamps besides AD-844. Lastly, the three IC based realization utilizes dual-output operational amplifier and two AD 844s.

It is also to be emphasized that the realizations of Fig. 2 and Fig. 3 effectively utilize the input following (Y-to-X voltage transfer) feature of AD844. The current following feature (X-to-Z transfer) in one of the AD844 of only Fig. 2 (c, d and g) is not being used, thus leaving further flexibility for tapping the unused Z current. Similarly, output follower (Z-to-W transfer) feature in these three realizations Fig. 2(c, d and g) is unused in one of the four AD844s allowing for further enhancements. With the availability of these features, the proposals can be good choice for mixed-mode circuit designs ensuring desirable output impedances for voltage and current signals.

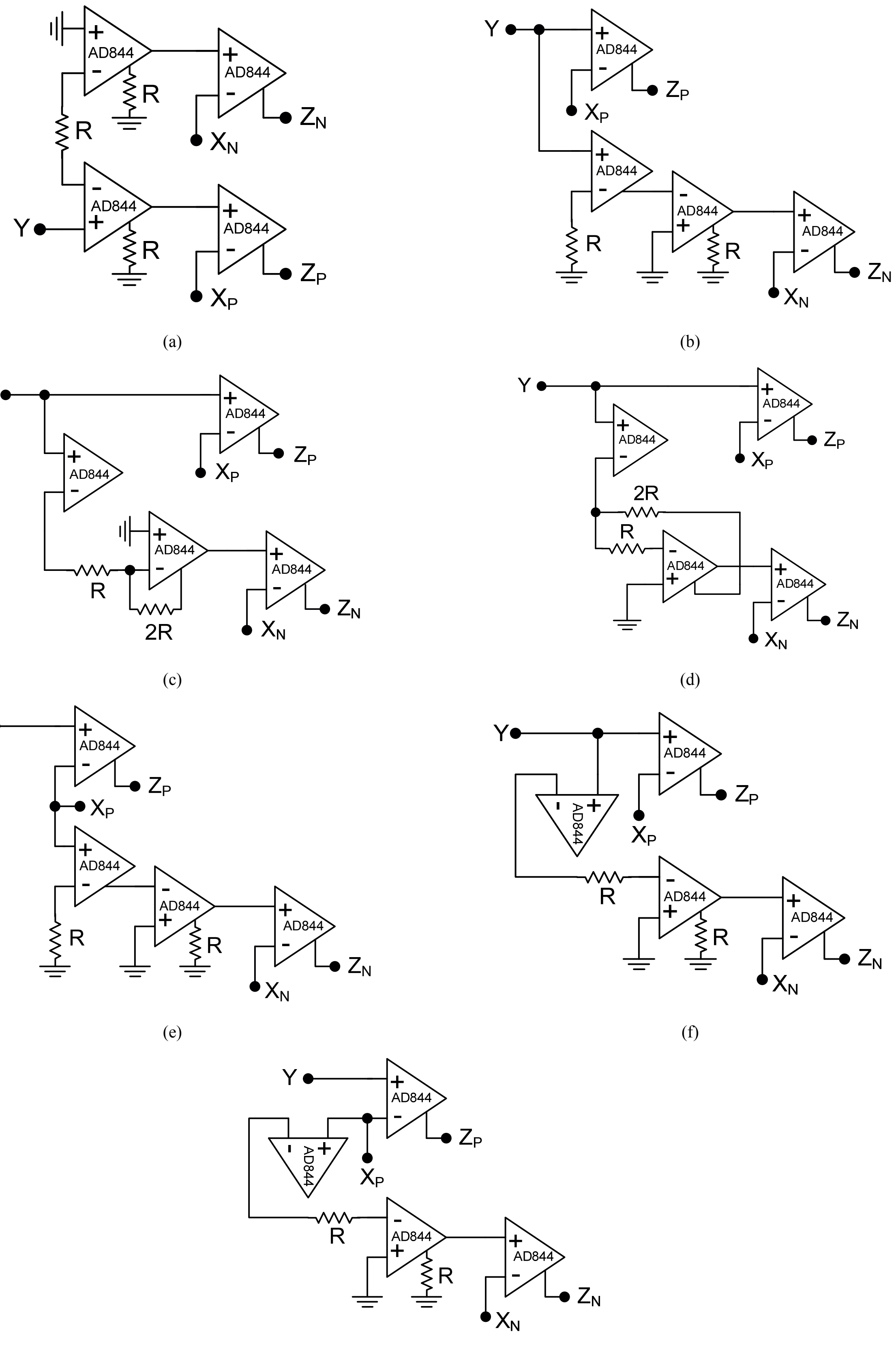

Fig. 2. Proposed DXCCII implementations employing only AD844s.

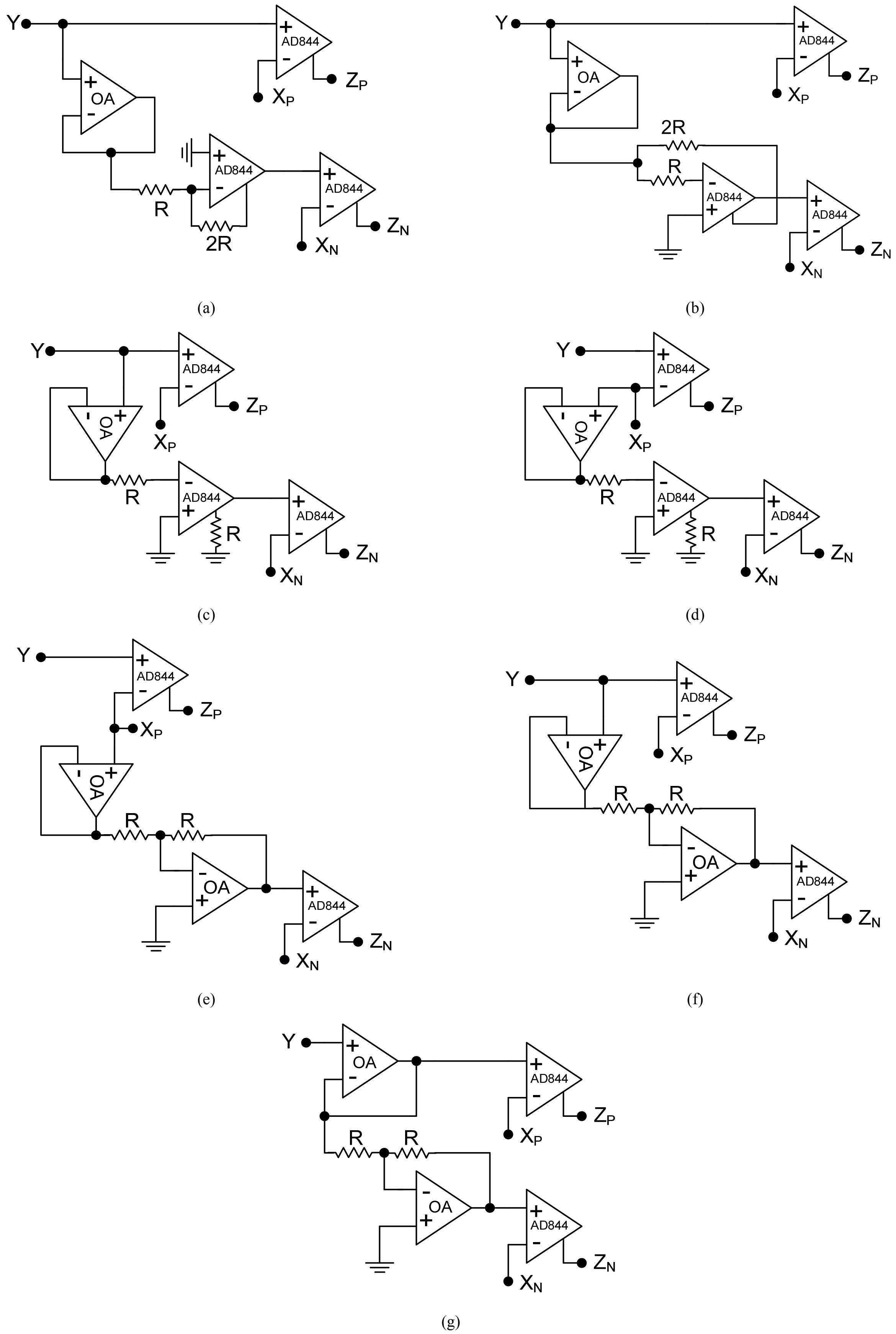

Fig. 3. Proposed DXCCII implementations employing AD843 opamps and AD844s.

	β_1	β_2	α_1	α_2	$f_{\beta 1}$ (MHz)	$f_{\beta 2}$ (MHz)	$f_{\alpha 1}$ (MHz)	$f_{\alpha 2}$ (MHz)
Fig. 2(a)	0.97	-0.97	1.00	1.00	7.035	6.061	4.368	4.132
Fig. 2(b)	0.99	-0.98	1.00	1.00	123.602	7.017	7.175	4.363
Fig. 2(c)	0.99	-0.98	1.00	1.00	144.112	5.603	7.175	4.452
Fig. 2(d)	0.99	-0.95	1.00	1.00	168.160	3.084	7.175	2.638
Fig. 2(e)	0.99	-0.97	1.00	1.00	93.140	7.011	7.176	4.363
Fig. 2(f)	0.99	-0.97	1.00	1.00	91.825	6.061	7.175	4.132
Fig. 2(g)	0.99	-0.96	1.00	1.00	168.160	6.062	7.176	4.132

Tab. 1. Performance parameters for the realizations using only AD844s as shown in Fig. 2.

	β_1	β_2	α_1	α_2	$f_{\beta 1}$ (MHz)	$f_{\beta 2}$ (MHz)	$f_{\alpha 1}$ (MHz)	$f_{\alpha 2}$ (MHz)
Fig. 3(a)	0.99	-0.99	1.00	1.00	136.449	5.924	6.812	4.323
Fig. 3(b)	0.99	-0.96	1.00	1.00	126.811	2.844	6.812	2.448
Fig. 3(c)	0.99	-0.97	1.00	1.00	127.114	5.929	6.819	3.969
Fig. 3(d)	0.99	-0.96	1.00	1.00	16.166	5.764	5.276	3.913
Fig. 3(e)	0.99	-0.98	1.00	1.00	21.748	3.184	5.275	3.073
Fig. 3(f)	0.99	-0.99	1.00	1.00	128.952	2.941	6.436	2.704
Fig. 3(g)	0.99	-0.99	1.00	1.00	11.517	3.826	6.598	6.124

Tab. 2 Performance parameters for the realizations employing AD844 and AD843 opamps as shown in Fig. 3.

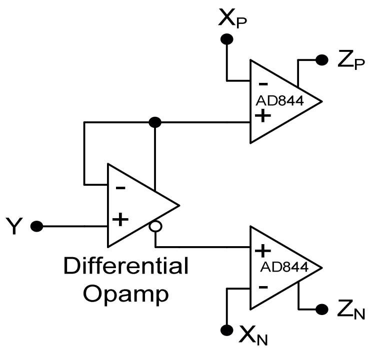

Fig. 4. Proposed DXCCII implementation employing a differential opamp and AD844s.

3. Verification of the Proposed Realizations

The catalog of realizations for DXCCII has first been verified through simulations using the PSPICE inbuilt models of the commercial ICs. The model of AD-844 is used for the realizations of Fig. 2 whereas for the realizations of Fig. 3, besides AD-844, AD-843 operational amplifier model is also employed [17]. It may be noted that AD-843 is the traditional voltage opamp exhibiting good compatibility with AD-844 [17]. Fig. 4 presents the DXCCII realization for the case where a differential output opamp is available. The supply voltage used was ±12V. The external resistors (R) employed in the proposed realizations were taken as 4.7 kΩ. The practical performance parameters of a DX-CCII namely the voltage and current transfer gains modify the terminal characteristics given in (1) to

$$\begin{bmatrix} I_Y \\ V_{XP} \\ V_{XN} \\ I_{ZP} \\ I_{ZN} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta_1 & 0 & 0 \\ -\beta_2 & 0 & 0 \\ 0 & \alpha_1 & 0 \\ 0 & 0 & -\alpha_2 \end{bmatrix} \begin{bmatrix} V_Y \\ I_{XP} \\ I_{XN} \end{bmatrix}. \tag{3}$$

Here, β_1 is the voltage transfer gain from Y to X_P, β_2 is the voltage transfer gain from Y to X_N. Similarly, α_1 is the current transfer gain from I_{XP} to I_{ZP} and α_2 is the gain from I_{XN} to I_{ZN}. It may further be noted that these voltage and current transfer gains have a DC value close to unity and are frequency dependent, with a one-pole roll-off.

The -3dB frequency for two voltage transfer gains may be denoted as $f_{\beta 1}$ and $f_{\beta 2}$ respectively, whereas the two current transfer gains may be denoted as $f_{\alpha 1}$ and $f_{\alpha 2}$ respectively. The performance parameters for the realizations of Fig. 2 based on AD-844 only are measured and listed in Tab. 1. Similarly, the performance parameters for the proposed realizations of Fig. 3 are also measured through simulations. Besides AD-844, the model of voltage opamp AD-843 is used for the purpose. The same are listed in Tab. 2.

4. DXCCII Enhancements

A few feature enhancements and applications of the active element DX-CCII, for which fifteen practical realizations were proposed in the earlier sections, are next discussed.

4.1 DXCCII with Buffered Outputs

All the proposed hardware realizations presented in Fig. 2 have an added feature which is not present in a conventional DXCCII available in the technical literature. The added feature is the availability of buffered voltage outputs corresponding to the voltages appearing at Z_P and Z_N terminals. These additional outputs are generated since the output stages of the DXCCII are implemented with AD-844s in which voltage-mode buffered outputs are inherently available. Fig. 3 shows the symbolic diagram of a modified DXCCII in which the buffered outputs are shown explicitly.

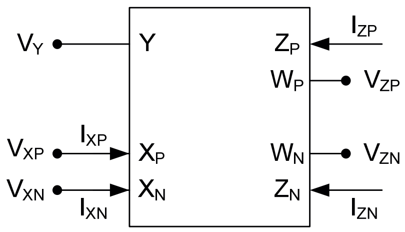

Fig. 5. DXCCII with buffered outputs.

4.2 Gain Variable DXCCII

A feature enhancement that is available in one of the proposed realizations of the DXCCII is discussed next. Considering the realization shown in Fig. 2(a) it may be observed that the voltage transfer gains from Y to X_P and X_N can be made controllable employing a variable resistance in place of the fixed valued floating resistance R shown in Fig. 2(a). The modification appears in Fig. 6 below.

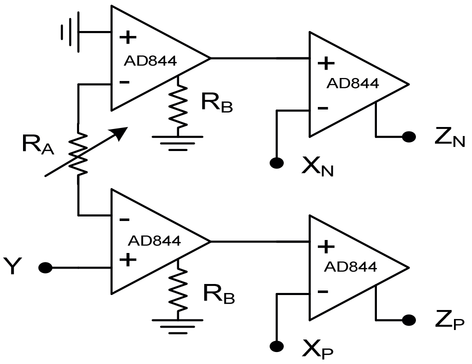

Fig. 6. Proposed Gain variable DXCCII.

It is evident from Fig. 6 that the voltage transfer gain from Y to X_P and X_N can now be given as

$$k = \frac{R_B}{R_A} \qquad (4)$$

This control over k through an external resistance would add more versatility to the DXCCII based circuits implemented using the proposed realization. In other words, the DXCCII can be imparted inherent tunability, which has been a feature of other active building blocks, like CCCIIs, CCCDBAs etc.

5. Application Examples

5.1 Quadrature Oscillator using DXCCII with Buffered Outputs

The DXCCII with buffered outputs obtained in the earlier section is next used for designing a simple yet novel oscillator circuit. The purpose here is to introduce an application of DXCCII along with its verification using one of the proposed realizations. Though the proposed oscillator is novel, a detailed comparison with available oscillators is not to be attempted here. However, the topic of oscillator realization is still a favorable choice of researchers, as evident from some recent literature and the ones cited therein [11, 18-29]. Amongst these are some recent works where DXCCII-based oscillator circuits have been proposed which require two DXCCII and several passive components [28, 29]. The circuit proposed in this paper as shown in Fig. 7 enjoys a compact structure with single DXCCII and four passive components.

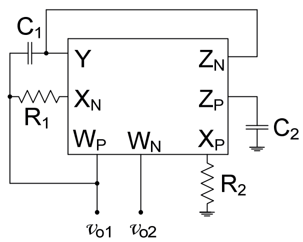

Fig. 7. Proposed Quadrature Oscillator using DXCCII with buffered outputs.

The circuit analysis yields the following second order characteristic equation

$$s^2 + s\left(\frac{1}{C_1R_1} - \frac{1}{C_2R_2}\right) + \frac{1}{C_1R_1C_2R_2} = 0. \qquad (5)$$

The frequency of oscillation (FO) and the condition of oscillation (CO) are

FO: $$f_o = \frac{1}{2\pi\sqrt{C_1R_1C_2R_2}}, \qquad (6)$$

CO: $$C_2R_2 \le C_1R_1. \qquad (7)$$

The two voltage outputs are related as

$$V_{o2} = +jmV_{o1} \qquad (8)$$

where

$$m = 2\pi f_o R_2 C_2. \qquad (9)$$

Alternatively m may also be expressed as ratio of two RC time constants after substituting FO from (6) in (9). The resulting m would then be $m = \sqrt{(R_2C_2/R_1C_1)}$. By ensuring equal time constants as also dictated through (7), m is found to be 'unity', thereby generating the quadrature outputs with equal amplitudes.

It is quite obvious that the circuit's simplicity and low component count does not permit non-interactive control over FO and CO, but the new circuit does serve the motive of this paper, by offering an application example to be verified through one of the proposed realizations of the active element used. The circuit (a) is selected from Fig. 2 for carrying out experimental verification. The supply voltage used was ±12 V. The value of R used in DXCCII implementation was 4.7 kΩ. The oscillator circuit was designed with $C_1 = C_2 = 100$ pF and R_1, R_2 as 2.2 kΩ, with R_1 adjusted so as to maintain the CO. It may be noted that both the voltage outputs are available at low impedance nodes.

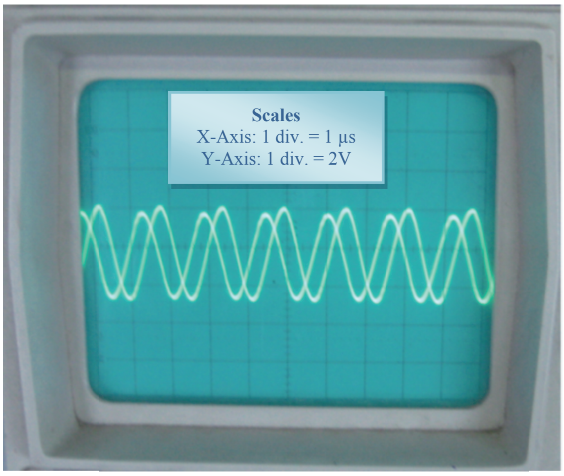

Fig. 8. Result of experimental verification of the proposed DXCCII based Quadrature Oscillator.

The quadrature outputs are shown in Fig. 8, from which the oscillation frequency was measured to be 666.66 kHz which is quite near to the design value of 695.6 kHz corresponding to $C_1 = 102$ pF, $C_2 = 104$ pF and $R_2 = 2.22$ kΩ (the measured values of the chosen components). The practical workability of the proposed realizations and the application built around it is thus verified.

5.2 Single Resistance Controlled Quadrature Oscillator

The variability of voltage transfer gain from Y to X_P and X_N in the realization of DXCCII was utilized in the circuit of Fig. 7 to alleviate the disadvantage of interactive control of *CO* and *FO*. Routine analysis of the circuit considering $k = R_B/R_A$ results in *FO* being given as

$$\text{FO:} \quad f_o = \frac{\sqrt{k}}{2\pi\sqrt{C_1 R_1 C_2 R_2}} \tag{10}$$

with the *CO* remaining the same as given in (7). Single resistance control of the frequency of oscillation through R_A was verified using breadboard implementation of the circuit of Fig. 7 using the gain variable DXCCII of Fig. 6. The value of R_B was chosen to be 4.7 kΩ (measured value is 4.6 kΩ) and various available values of resistors between 2 kΩ and 10 kΩ were employed as R_A. The *FO* variation with R_A is listed as Tab. 3 where the theoretical frequency is the one obtained using (10) by substituting the values of the chosen passive elements as mentioned above. Fig. 9 shows the same with very convincing agreement with the theoretical values, the causes of deviation being discussed in the sub-section that follows.

R_A (KΩ)	*k*	*FO* (Theoretical) (KHz)	*FO* (Experimental) (KHz)
2.11	2.18	1026.18	909.09
2.98	1.55	863.49	769.23
3.15	1.46	839.86	769.23
3.79	1.22	765.67	714.29
4.64	0.99	692.00	666.67
5.30	0.87	647.48	625.00
6.43	0.72	587.84	555.56
8.61	0.54	508.00	476.19
8.86	0.52	500.78	454.55

Tab. 3. Frequency Control using a single resistance.

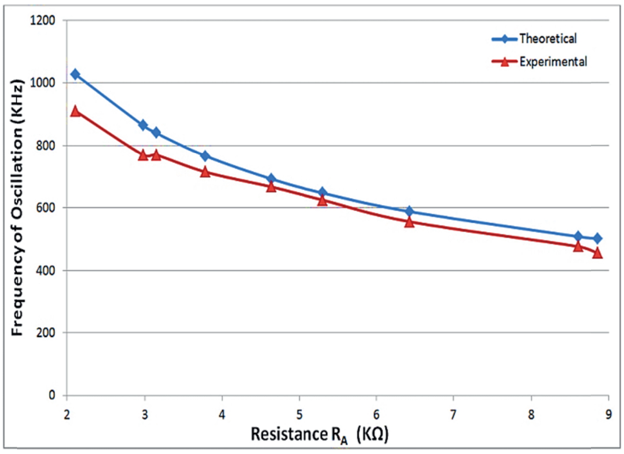

Fig. 9. Comparison of experimental and theoretical results for the oscillator of Fig. 7.

5.3 Parasitic Effects on Oscillator Performance

As evident from Tab. 3, the discrepancy between theoretical and experimental *FO* reduces with increasing values of R_A. This is quite justifiable in view of the X-terminal resistances of AD 844s [17], which merge with R_A (please refer to Fig. 6). With increasing R_A, this effect reduces thereby reducing the discrepancy between the theoretical and experimental values.

It may further be noted that experimental *FO* is less than the theoretical one because the parasitic X-terminal resistances at X_P and X_N merge with R_2 and R_1 respectively, thereby effectively increasing their values. Similarly, the Z-terminal parasitic capacitance also appears along with C_2 increasing its value. These increments in R_1, R_2 and C_2 cause reduction in the experimental FO as compared with theoretical FO. This can be explained as follows. Considering Fig. 7, the effective values of the resistances R_1 and R_2 after considering the inclusion of parasitic X-terminal resistances may be given by

$$R_{1,\text{eff}} = R_1 + R_{XN}\,, \tag{11}$$

$$R_{2,\text{eff}} = R_2 + R_{XP}\,, \tag{12}$$

$$C_{2,\text{eff}} = C_2 + C_{ZP}\,. \tag{13}$$

Now, incorporating the inverting terminal resistance of AD844s which merge with R_A, its effective value becomes

$$R_{A,\text{eff}} = R_A + 2R_X \tag{14}$$

where R_X refers to the intrinsic resistance associated with the inverting terminal of the AD844s, to which R_A is connected. From (4) and (14) the modified value of k becomes

$$k_{\text{eff}} = \frac{R_B}{R_{A,\text{eff}}}\,. \tag{15}$$

Now from (11) – (15), the expression of FO, as given in (10), is modified to

$$\text{FO:} \qquad f_o = \frac{\sqrt{k_{\text{eff}}}}{2\pi\sqrt{C_1 C_{2,\text{eff}} R_{1,\text{eff}} R_{2,\text{eff}}}}\,. \tag{16}$$

It is quite evident from (16) that *FO*(Experimental) in Tab. 3 would be slightly lower than *FO*(Theoretical), thus further justifying the authenticity of the tabulated results.

6. Conclusion

This paper is a first attempt to present fifteen distinct implementations of a useful active element in form of DX-CCII using commercially available ICs. Detailed results are presented for the proposed implementations. Various optional features like the availability of buffered outputs and gain variability through a single resistance are also discussed. A quadrature oscillator is built around one DXCCII and passive elements using one of the proposed realizations. Experimental results for the oscillator are also presented with convincing results. Further, the gain variability by a single resistance is exploited to control the oscillation frequency of the proposed oscillator by employing the gain-variable DXCCII. The topic of active-RC networks continues to find most recent space in technical literature [30]-[34].

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