Realization of Current Mode Universal Filter and a Dual-Mode Single Resistance Controlled Quadrature Oscillator Employing VDCC and Only Grounded Passive Elements

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Abstract. The manuscript presents a circuit that can act as a universal filter as well as a single resistance controlled oscillator by unpretentiously changing the switch positions. The circuit employs only two active devices and all grounded passive elements. The utilization of only grounded passive components makes this circuit a better choice for integrated circuit implementation. The current mode biquadratic filter offers all the five basic responses along with independent tunability of its quality factor. The dual-mode quadrature sinusoidal oscillator offers explicit current outputs along with voltage outputs. The circuit also offers a simple and uncoupled condition of oscillation and frequency of oscillation. The typical analysis such as non-ideal, sensitivity and parasitic analysis along with the regular simulation results as well as experimental results are exposed here, to strengthen the design idea.

Keywords
Current Mode circuits, single resistance controlled oscillator, universal filter, voltage differencing current conveyor.

1. Introduction

From last few decades, there has been a predominance of digital signal processing over analog signal processing. But this does not pose any threat to it; rather it gave more challenges and opportunity to the designer and researcher of analog circuits. Analog signal processing, where natural/ analog signals are handled as per the specifications, has its own advantages such as higher bandwidth, faster speed of operation etc. In the domain of analog circuits, some of the most widely employed applications are active filters, sinusoidal oscillator, non-linear waveforms generator, synthetic inductor realization [1], [2], [3], [4] and [5]. Frequency selective filters and sinusoidal oscillator, since long, have found impeccable application in communication receiver, control systems etc. [6]. Frequency selective filters, as the name implies, is the block that passes/attenuates any specific frequency or a band of frequencies whereas oscillator is a circuit that generates the undamped waveform of any designed frequency.

The reference no. [7] exposed a gateway to the upcoming future devices; Voltage Differencing Current Conveyor (VDCC) is one of them. So many applications of this active device [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] and [22], and references cited therein, are made available in the open literature. But still as per authors’ perception, this active device has to be much more explored and exploited for analog signal processing applications, in future.

Out of these [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] and [22], synthetic inductor is realized in [8], [9] and [10], passive element simulator in [11] and [12], active filter was presented in [13], [14], [15], [16] and [17], and sinusoidal oscillator in [18], [19], [20] and [21]. The behavioral model of the active device is discussed in detail in [22]. Comparison of the designed universal filter circuit with the earlier work done on VDCC based filters is as follows. In [13] a voltage mode universal active filter using single
VDCC is presented but it suffers from the drawback of the utilization of floating passive elements. A current mode universal filter with less number of active devices is presented in [14] but the circuit has a drawback that the filter parameters are not independently tunable. The circuit given in [15] uses the same number of active and passive devices but input current is not injected at low impedance port. Additionally, circuit can perform one function only. In [16] higher numbers of passive elements were used. First ever, first order all-pass filter using single VDCC is presented in [17]. A qualitative comparison of parameters with given literature survey is shown in Tab. 1.

Now the comparison of the proposed oscillator with the earlier published work is given as follows. The quadrature oscillator, employing all grounded passive elements, which is not having non-interacting CO and FO (also known as fully uncoupled) and its tuning capability is limited with passive grounded element only, is presented in [18] and [21]. In [19], the same number of active and passive elements are utilized, but works as a sinusoidal oscillator only (can’t perform the function of active filter). In [20], a multiphase oscillator using controlled gain VDCC was proposed but requires a matching condition to the linear control of oscillation frequency. A comparative analysis is also presented in Tab. 2.

The purpose of this manuscript is to present one such circuit that can work as a universal filter along with a sinusoidal oscillator. In conclusion, the circuit offers various features, when used as an active filter, such as:

- Availability of all five responses in current mode i.e. low pass, high pass, band pass, band reject and all pass filter function.
- Independent tunability of its quality factor (Q₀).
- Orthogonal tunability of its center frequency (ω₀).
- Availability of explicit current output.
- Use of only grounded passive elements.
- Availability of low impedance at input port and high impedance at output port.

Whereas when the same circuit acts as sinusoidal oscillator reflects some useful characteristics e.g.

- Availability of explicit current output.
- Use of only grounded passive elements.
- Availability of quadrature current output (explicit).
- Availability of voltage mode quadrature output.
- Simple Condition of Oscillation (CO) and Frequency of Oscillation (FO).
- Uncoupled CO and FO.
- FO can be tuned either electronically or by use of grounded passive resistor.
- CO can also be adjusted by grounded passive resistor or by electronic tunability.
Full manuscript is divided into five main sections. At the outset, the present section gives the introduction of analog signal processing and comparison between previous work and presented work. Section 2. presents the active device i.e. VDCC along with the proposed circuit. Non-ideal and sensitivity analysis is depicted in Sec. 3. Section 4. states the effects of parasitic of the active device under consideration, on the proposed circuit. To verify the theoretical analysis, Sec. 5. contains all the simulation results. Experimental results are given in Sec. 6. At last, conclusion is provided in Sec. 7.

2. Proposed Circuit

The electrical combination of an Operational Transconductance Amplifier (OTA) and a second generation Current Conveyor (CCII) is known as VDCC. The block diagram along with its functional circuit diagram, employing CMOS transistors, are shown in Fig. 2 and Fig. 1 respectively. Equation (1) represents the natural characteristics of the active device. Here $g_{m}$ is the transconductance factor of the device; additionally, this is electronically tunable with the help of the bias current i.e. $I_{B1}$ (Fig. 2).

\[
\begin{bmatrix}
I_P \\
I_N \\
I_{Z} \\
V_{X} \\
I_{WP} \\
I_{WN}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
g_{m} - g_{on} & 0 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & -1
\end{bmatrix}
\begin{bmatrix}
V_{P} \\
V_{N} \\
V_{Z} \\
I_{X}
\end{bmatrix}.
\]  

The proposed circuit that can work as a current mode universal filter, as well as single resistance controlled oscillator, by simply altering the switch position, is shown in Fig. 3. Table 3 shows the basic combination of switches, as shown in Fig. 3, so that the circuit can provide the desired nature of the operation.

![Fig. 1: MOS realization of the Voltage Differencing Current Conveyor [15].](image1)

![Fig. 2: Block Diagram of VDCC [8].](image2)

![Tab. 3: Characteristic table (for the circuit shown in Fig. 3).](table3)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Switches</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current mode universal filter</td>
</tr>
<tr>
<td>2.</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual mode quadrature oscillator</td>
</tr>
</tbody>
</table>

When the switch combination as given in S.No. 1 of Tab. 3 is applied, the circuit behaves as an active filter. To get all the desired transfer functions, we simply apply the basics of circuit theory on the Fig. 3, utilizing the characteristic equation of VDCC i.e. given in Eq. (1). All five desired transfer function of a universal filter i.e. low pass, high pass, band pass, band stop...
and all are presented in Eq. (2), Eq. (3), Eq. (5), Eq. (7) and Eq. (9). The common denominator polynomial, expressed for the center frequency and quality factor are given by Eq. (10), Eq. (11) and Eq. (12). It is evident from Eq. (12) that the \( Q_0 \) is independent of \( \omega_0 \) and its value can be varied by varying a grounded passive resistor i.e. \( R_0 \). The gain of the given Band Pass (\( H_{BP} \)) and Low Pass (\( H_{LP} \)) filter function is given in Eq. (13).

\[
\frac{I_{OUT}}{I_{IN}} = \frac{I_{BP}}{I_{IN}} = \frac{s \cdot g_{m1}}{C_0} \frac{D(s)}{D(s)}.
\]

\[
\frac{I_{OUT}}{I_{IN}} = \frac{I_{LP}}{I_{IN}} = \frac{g_{m1}}{R_1 C_0 C_1} \frac{D(s)}{D(s)}.
\]

If \( g_{m1} R_0 = 1 \),

\[
I_{HP} = -I_{IN} + I_{BP} + I_{LP},
\]

\[
\frac{I_{HP}}{I_{IN}} = -\frac{s^2}{D(s)},
\]

\[
I_{BS} = I_{HP} - I_{BP},
\]

\[
\frac{I_{BS}}{I_{IN}} = -\frac{s^2 + \frac{s}{R_0 C_0}}{D(s)}.
\]

\[
I_{AP} = -I_{HP} - I_{BP} + I_{LP},
\]

\[
\frac{I_{AP}}{I_{IN}} = \frac{s^2 - \frac{s}{R_0 C_0} + \frac{g_{m1}}{R_1 C_0 C_1}}{D(s)}.
\]

\[
D(s) = s^2 + \frac{s}{R_0 C_0} + \frac{g_{m1}}{R_1 C_0 C_1}.
\]

\[
\omega_0 = \sqrt{\frac{g_{m1}}{R_1 C_0 C_1}}.
\]

\[
Q_0 = R_0 \sqrt{\frac{g_{m1} C_0}{R_1 C_1}}
\]

\[
H_{LP} = 1,
\]

\[
H_{BP} = g_{m1} R_0
\]

where \( \omega_0 \) is the center frequency in rad s\(^{-1} \) and \( Q_0 \) is the quality factor.

When the appropriate switch combination of Tab. 3 (S.No.2) is applied, the proposed circuit works as a Single Resistance Controlled Oscillator (SRCO). The characteristic equation of the proposed SRCO is given by Eq. (14). The Condition of Oscillation (CO) and Quality of Oscillation (FO) are simple and uncoupled to each other, represented by Eq. (15) and Eq. (16) respectively. Here, it is evident that the CO, as well as FO, can be tuned electronically \((g_{m0} \text{ for CO and } g_{m1} \text{ for FO})\) as well as with the help of grounded passive resistor \((R_0 \text{ for CO and } R_1 \text{ for FO})\), without affecting each other. The circuit offers two explicit current outputs that are in 90° phase shift to each other. These two quadrature outputs are \( I_{OUT} \) and \( I_{OUT1} \). The relationship between them is shown by Eq. (17). Here it is worth noting that the derived circuit can also offer quadrature voltage outputs \( V_a \) and \( V_b \). The relationship between the both is justified by Eq. (18).

\[
s^2 + \frac{s}{C_0} \left( \frac{1}{R_0} - g_{m0} \right) + \frac{g_{m1}}{R_1 C_0 C_1} = 0.
\]

\[
C.O. \quad \left( \frac{1}{R_0} - g_{m0} \right) = 0.
\]

\[
F.O. \quad \omega_0 = \sqrt{\frac{g_{m1}}{R_1 C_0 C_1}}.
\]

\[
\frac{I_{OUT}}{I_{OUT1}} = \frac{1}{s C_1 R_1}.
\]

\[
\frac{V_b}{V_a} = \frac{g_{m1}}{s C_1}.
\]

### 3. Non-Ideal and Sensitivity Analysis

The deviation between ideal and non-ideal values of the active device can be checked through its given mathematical equation. Equation (19) represents the characteristic equations of VDCC where \( 'i' \) represents the number of the active device that could be 0 and 1. The non-ideal factors are defined as \( \alpha, \beta, \gamma_P \) and \( \gamma_N \). The ideal values of \( \alpha, \beta, \gamma_P \) and \( \gamma_N \) are in unity only.

\[
\begin{align*}
I_Z = \alpha_1 \cdot g_{m1}(V_P - V_N) \\
V_X = \beta_1 \cdot V_Z \\
I_{WP} = \gamma_P I_X \\
I_{WN} = -\gamma_N I_X
\end{align*}
\]

When Eq. (19) is used for analyzing the proposed circuit, as given in Fig. 3 by circuit theory fundamentals, non-ideal transfer functions are obtained. Equations (20) and Eq. (21) represent the transfer functions of band pass and low pass filters, whereas, frequency and quality factor along with common denominator polynomial are given by Eq. (22), Eq. (23) and Eq. (24).

\[
\frac{I_{OUT}}{I_{IN}} = \frac{\alpha_1 \cdot \gamma_{NO} \left( \frac{s Q_{m1}}{C_0} \right)}{D'(s)}.
\]

\[
\frac{I_{OUT}}{I_{IN}} = \frac{\alpha_1 \cdot \beta_1 \cdot \gamma_{PO} \cdot \gamma_{NO} \left( \frac{g_{m1}}{C_0 C_1 R_1} \right)}{D'(s)}.
\]
\[ \omega_0 = \sqrt{\frac{\alpha_1 \cdot \beta_1 \cdot g_{m1} \cdot \gamma N_1}{C_0 C_1 R_1}}. \tag{22} \]

\[ Q_0 = R_0 \sqrt{\frac{C_0 \alpha_1 \cdot \beta_1 \cdot g_{m1} \cdot \gamma N_1}{C_1 R_1}}. \tag{23} \]

\[ D'(s) = s^2 + s \left( \frac{1}{C_0 R_0} \right) + \frac{\alpha_1 \cdot \beta_1 \cdot g_{m1} \cdot \gamma N_1}{C_0 C_1 R_1}. \tag{24} \]

While doing the non-ideal analysis for the proposed sinusoidal oscillator, we get the following characteristic equation, given by Eq. (25). From Eq. (25), non-ideal CO and FO can be easily deduced, which are represented in Eq. (26) and Eq. (27) respectively.

\[ s^2 + \frac{1}{C_0} \left( \frac{1}{R_0} - \alpha_0 \cdot g_{m0} \right) + \frac{\alpha_1 \cdot \beta_1 \cdot g_{m1} \cdot \gamma N_1}{R_1 C_0 C_1} = 0. \tag{25} \]

\[ \text{C.O.} \left( \frac{1}{R_0} - \alpha_0 \cdot g_{m0} \right) \geq 0. \tag{26} \]

\[ \text{F.O.} \quad \omega_0 = \sqrt{\frac{\alpha_1 \cdot \beta_1 \cdot g_{m1} \cdot \gamma N_1}{R_1 C_0 C_1}}. \tag{27} \]

Sensitivity analysis was also carried out for both the proposed applications of VDCC. The sensitivity equations for the derived current mode universal filter are given by Eq. (28), Eq. (29), Eq. (30), Eq. (31), Eq. (32) and Eq. (33) and for SRCO derived sensitivity equations are represented by Eq. (34) to Eq. (35). All the derived sensitivity figures are under considerable limits.

\[ S_{\alpha_1}^0 = S_{\beta_1}^0 = S_{\gamma N_1}^0 = \frac{1}{2}. \tag{28} \]

\[ S_{g_{m1}}^0 = \frac{1}{2}; \quad S_{R_1}^0 = S_{C_1}^0 = S_{C_0}^0 = -\frac{1}{2}. \tag{29} \]

\[ S_{\alpha_1}^C = S_{\beta_1}^C = S_{\gamma N_1}^C = \frac{1}{2}. \tag{30} \]

\[ S_{g_{m1}}^C = S_{R_1}^C = S_{C_1}^C = S_{C_0}^C = \frac{1}{2}. \tag{31} \]

\[ S_{\alpha_1}^R = S_{\beta_1}^R = \frac{1}{2}. \tag{32} \]

\[ S_{\alpha_1}^C = S_{\beta_1}^C = S_{\gamma N_1}^C = \frac{1}{2}. \tag{33} \]

\[ S_{g_{m1}}^0 = S_{R_1}^0 = S_{C_1}^0 = S_{C_0}^0 = -\frac{1}{2}. \tag{34} \]

\[ S_{g_{m1}}^1 = S_{R_1}^1 = S_{C_1}^1 = S_{C_0}^1 = \frac{1}{2}. \tag{35} \]

**Fig. 4:** Parasitic model of VDCC [19].

### 4. Parasitic Analysis

A well known parasitic model of VDCC [19] has been taken into consideration, shown in Fig. 4, to explore the effect of parasitic on designed circuits.

The next scheme shows the proposed circuit including parasitic effects. It is evidently shown that the proposed current mode universal filter and sinusoidal oscillator reflects good performance under the influence of parasitic.

#### 4.1. Parasitic Analysis for Universal Filter

\[ R_a = R_1 + R_{X1}. \]

\[ R_b = R_0 || R_{N0} || R_{N1}. \]

\[ C_a = C_0 + C_{N0} + C_{N1}. \]

\[ I_{OUT1} = \frac{1}{\frac{1}{R_{Z1}} + sC_1} \frac{g_{m1}}{C_0 C_1} \frac{1}{D(s)}. \]

\[ I_{OUT} = \frac{R_a C_1 C_0}{D(s)}. \]
4.2. Parasitic Analysis for Sinusoidal Oscillator

Assumptions:

\[ R_a = R_1 + R_{X1}. \]

\[ R_b = R_0||R_{Z0}||R_{N1}. \]

\[ C_a = C_0 + C_{N1}. \]

CO: \( \frac{1}{C_a} [g_{m0} - R_b] = \frac{1}{C_1 R_{Z1}}. \)

FO: \( \bar{\omega}_0^2 = \frac{1}{C_a C_1} \left[ \frac{1}{R_{Z1}} \left( \frac{1}{R_b} - g_{m0} \right) + \frac{g_{m1}}{R_a} \right]. \)

\[ S_{R_a}^w = -S_{g_{m1}}^w = -\frac{1}{2} \frac{g_{m1}}{R_a C_a R_{Z1} R_b} \]

\[ S_{R_b}^w = \frac{1}{2} \frac{g_{m1}}{R_a C_a R_{Z1} R_b} \left( \frac{1}{R_b} - g_{m0} \right) + \frac{g_{m1}}{R_a} \]

\[ S_{g_{m0}}^w = \frac{1}{2} \frac{g_{m0}}{R_a C_a R_{Z1} R_b} \left( \frac{1}{R_b} - g_{m0} \right) + \frac{g_{m1}}{R_a} \]

\[ S_{C_1}^w = S_{C_a}^w = -\frac{1}{2} \]

5. Simulation Results

Feasibility of the proposed filter cum oscillator circuit, with all grounded passive components, has been tested and simulated using Cadence PSPICE simulation software. The CMOS version shown in Fig. 1, using 0.18 µm TSMC MOS process parameters [23], is utilized for generating the graphical results. The aspect ratios, used in Fig. 1, are presented in Tab. 4 [8]. For simulation, supply voltage of ±0.9 V and bias current of 50 µA (I_{B1}) and 100 µA (I_{B2}), shown in Fig. 4, are used and the corresponding value of transconductance gain (g_m) is 277 µA-V^{-1}. All the simulation results of the derived circuit are mainly divided into two parts - former depict universal filter’s simulation results and latter shows the simulation graphs for the oscillator circuit.

For the testing of the universal filter, the passive components were selected as \( R_0 = R_1 = 3.6 \) kΩ, \( C_0 = 21.9 \) pF, \( C_1 = 87.6 \) pF and the transconductance gain of the active device is 277 µA-V^{-1}. Figure 5 demonstrates that the designed current mode circuit can be utilized as a low pass, high pass, band pass and band stop filter. Here the center frequency was chosen as 1 MHz and the value of the quality factor is 0.5. The proposed circuit can also act like an all pass filter whose gain as well as phase response is depicted in Fig. 6. Figure 5 and Fig. 6 collectively justify the design of a universal filter using VDCC with all grounded passive components. As given in Eq. (12), \( Q_0 \) can be varied with the help of resistance \( R_0 \) without altering the center frequency. So the variation of the quality
factor by changing the value of grounded passive resistor $R_0$ is shown in Fig. 7. Table 5 gives the range of $R_0$ and their corresponding value of $Q_0$.

**Tab. 4:** Aspect ratios of the MOS devices [8].

<table>
<thead>
<tr>
<th>CMOS transistors</th>
<th>W/L (in µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1–M4</td>
<td>3.6/1.8</td>
</tr>
<tr>
<td>M5, M6</td>
<td>7.2/1.8</td>
</tr>
<tr>
<td>M7, M8</td>
<td>2.4/1.8</td>
</tr>
<tr>
<td>M9, M10</td>
<td>3.06/0.72</td>
</tr>
<tr>
<td>M11, M12</td>
<td>9.0/0.72</td>
</tr>
<tr>
<td>M13–M17</td>
<td>14.4/0.72</td>
</tr>
<tr>
<td>M18–M22</td>
<td>0.72/0.72</td>
</tr>
</tbody>
</table>

**Tab. 5:** $Q_0$ tunability (passive Components values).

<table>
<thead>
<tr>
<th>$Q_0$</th>
<th>$R_0$ (in kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>1.8</td>
</tr>
<tr>
<td>0.35</td>
<td>2.54</td>
</tr>
<tr>
<td>0.5</td>
<td>3.6</td>
</tr>
<tr>
<td>0.707</td>
<td>5.09</td>
</tr>
<tr>
<td>1</td>
<td>7.2</td>
</tr>
<tr>
<td>1.414</td>
<td>10.18</td>
</tr>
</tbody>
</table>

Apart from $Q_0$ tunability, the center frequency of the designed filter can also be varied, as shown in Fig. 8. The passive elements values selected for Fig. 8 are given in Tab. 6. The transient response of the band pass filter is also simulated at 1 MHz, represented in Fig. 9. Figure 8 depicts that at input current of 25 µA, the output is distortion free. Total Harmonic Distortion (THD) of the designed current mode filter circuit is also calculated. The graph plotted between input current versus existing percentage of THD, is depicted in Fig. 10. Figure 10 shows that up to 80 µA of input current the THD is significantly low.

The proposed circuit can also be utilized as a single resistance controlled oscillator with all grounded components. The passive components values for the designed sinusoidal oscillator were chosen as $R_1 = 15$ kΩ, $C_0 = C_1 = 21.9$ pF and the transconductance gain of the active device is 277 µA.V$^{-1}$. The transient and the steady state responses, with explicit current output are shown in Fig. 11 and Fig. 12 respectively. Additionally, Fig. 12 represents the quadrature outputs in current mode. As discussed in Sec. 2, the designed oscillator can also deliver the voltage mode quadrature output, represented in Fig. 13. Lissajous patterns for the current and voltage mode quadrature outputs are also plotted in Fig. 14 and Fig. 15 respectively. It can be seen from last two figures that there are no tilts in the ellipses, hence verifying the quadrature relation-
Fig. 8: Variation of center frequency with fixed $Q_0$.

Fig. 9: Transient response of the band pass filter.

Fig. 10: THD curve for a band pass filter function.

ships. The measured phase angle is $88.3^\circ$ and $89.4^\circ$ respectively for Fig. 12 and Fig. 13.

Fig. 11: Transient response of the current mode sinusoidal oscillator.

Fig. 12: Steady state response of the quadrature current outputs.

Fig. 13: Steady state response of the quadrature voltage outputs.
The FFT representation of the explicit current output sinusoidal oscillator is shown in Fig. 16 (for better clarity and to see the availability of harmonics, y-axis has been taken in log domain). It is evident from Eq. (16) that the FO of the derived circuit can be varied with the help of grounded passive resistor i.e. $R_1$ and same can also be achieved by electronic tunability using $g_{m1}$. Figure 17 shows the variation of FO with respect to grounded resistor $R_1$ whereas Fig. 18 represents the electronic tunability of FO with respect to bias current of $g_{m1}$ i.e. $I_{B1}$. In Fig. 17 for the entire range of $R_1$ the FO is calculated and maximum error between simulated and calculated values of FO is found to be 6.78 % only. The variation of frequency, under the influence of parasitics, has also been computed. The values of parasitic elements ($R_X = 43 \ \Omega$, $R_2 = 362\ \text{k}\Omega$, $R_N = 141\ \text{k}\Omega$, $C_P = C_N = 0.92\ \text{pF}$) have been taken from [8]. In Fig. 18 for ideal frequency of 1.86 MHz (for $C_0 = C_1 = 21.9\ \text{pF}$, $R_1 = 3.6\ \text{k}\Omega$ and $g_{m1} = 236\ \mu\text{A}\cdot\text{V}^{-1}$ at $I_{B1}$ of 35 $\mu$A) we get the simulated value as 1.84 MHz and including the effect of parasitic we get the FO 1.82 MHz with an error of 2.58 % with respect of ideal frequency.

The total harmonic distortion was also calculated for the entire usable range of the sinusoidal oscillator, as shown in Fig. 19. Figure 19 depicts that the THD is significantly low for the entire range of frequencies which strengthens the designed idea. However, the fluctuation presented in Fig. 19 can be reduced by introducing an additional AGC network as given in [20].

6. Experimental Results

For practical implementation of VDCC as a block, a readily available integrated circuit i.e. OPA860 (see...
value of $R_{OFFSET}$ is also taken as 100 $\Omega$ (Fig. 13 of [13]).

For a generation of hardware results, we have used SCIENTIFIC Multiple power supply (PSD3304), SCIENTECH function generator (4061), SCIENTIFIC Oscilloscope (30 MHz, SM410). The passive component values, used in experimentation for the active filter, are $C_1 = C_2 = 470$ pF, $R_{m1} = 1/g_{m1} = 330$ $\Omega$ and $R_1 = R_0 = 330$ $\Omega$. For the implementation of SRCO following passive elements have been taken, $C_1 = C_2 = 470$ pF, $R_{m1} = 1/g_{m1} = R_{m0} = 1/g_{m0} = 330$ $\Omega$ and $R_1 = 330$ $\Omega$. Figure 20 and Fig. 22 respectively, shows the experimental setup for the active filter and sinusoidal oscillator using OPA860. The two (explicit) responses i.e. low pass and band pass are simulated using the PSPICE library file of OPA 860 obtained from www.ti.com The results obtained are very much close to reality, as one can see in Fig. 21 For the purpose of experimentation low pass and band pass (explicit outputs, obtained experimentally) are also marked in Fig. 21. The frequency of operation was chosen as 1 MHz. Figure 23 shows the steady state quadrature output of the experimentally realized oscillator using OPA860. Here the frequency of operation is also cho-
sen as 1.03 MHz (ideally) and the achieved frequency through simulation (using OPA860 macro model) is 935 kHz (with an error of 6.5 %). When the same is performed experimentally, the frequency of operation comes out to be 914 kHz (with an error of 2.2 % with respect to OPA860 simulation). To check the wide range of the oscillator, the graph between frequency of operation and a grounded passive resistor $R_1$ is plotted, shown in Fig. 24. The simulated and experimental values are in good agreement to each other.

![Steady state output of the oscillator](image)

**Fig. 23:** Steady state output of the oscillator.

![Variation of FO with respect to a grounded resistor](image)

**Fig. 24:** Variation of FO with respect to a grounded resistor $R_1$.

7. Conclusion

This manuscript presents a realization of a current mode universal filter and a single resistance controlled oscillator successively, by altering the positions of the passive switches. Both the designed circuits employ only grounded passive elements and two active devices. Availability of explicit current outputs makes it a better proposition. The designed universal filter can produce all the five basic responses along with independent control of its quality factor. The derived SRCO has quadrature outputs in current mode (explicit output) as well as in voltage mode. The CO and FO of the oscillator are totally uncoupled and can be governed by a passive grounded resistor. The additional electronic tunability of CO and FO is also available. Regular mathematical analysis and typical simulation and experimental results justify the theoretical idea.

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References


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