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Performance Analysis of Tunable Frequency Sinusoidal Oscillator Employing CCII+ Based AD844

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Abstract

This paper presents realization of canonic tunable frequency sinusoidal oscillator and its physical implementation using commercially available IC AD844. These oscillators employ second generation current conveyor as there functional block. State variable equation matrix are used to determine values of passive elements and give tuning law for oscillation. THD and DC component of generated waveform are used to determine the quality of sinusoidal wave.

1. Introduction

Single element controlled, specifically a resistor or in some cases a grounded capacitor, oscillator finds application in numerous of measurement and instrumentation. Such oscillators are also used to generate low frequency sinusoidal signal.

Current feedback operational Amplifiers (CFOAs) such as AD844 having four terminals, particularly the compensation terminal, have become more popular than traditional voltage mode op-amps (VOA). Advantages provided are such as nearly constant bandwidth independent of gain, higher slew rate, ease of designing circuits with generalized second order deferential equation for oscillators, low distortion level and least no. of external elements is attracting prominent circuit designers. The CFOAs used has a terminal characteristics that of second generation current conveyor CCII+ [1-6] characterized by hybrid matrix

$$\begin{bmatrix} i_Y \\ v_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} v_Y \\ i_X \\ v_Z \end{bmatrix}$$

Where x, y are input terminal and z is output terminal.

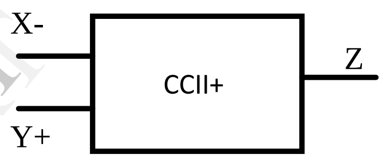

Fig.1. Second Generation Current Conveyor.

Although a no. of CFOAs based sinusoidal oscillators have been evolved[8-11,13-18] none of them employ both grounded resistors as well as capacitor. Here provided two CFOAs, condition for sinusoidal oscillators are characterized using state variable equation [11], in such a way that there is non-interacting control between condition of oscillation (CO) and frequency of oscillation(FO). The second order generalized state variable equation can be stated using eq. (1). Characteristics equation (CE) for oscillators is equal to zero so from (1) and (2) [i.e. for loop gain L(s)] we have eqn. (3).

$$\begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \quad (1)$$

$$1-L(s) = 0 \quad (2)$$

$$s^2 - (a_{11} + a_{22})s + (a_{11}a_{22} - a_{12}a_{21}) = 0 \quad (3)$$

From (3) condition of oscillation and frequency of oscillation can be given by (4) and (5)

$$(a_{11} + a_{22}) = 0 \quad (4)$$

Or $a_{11} = -a_{22}$

$$\omega_o = \sqrt{a_{11}a_{22} - a_{12}a_{21}} \quad (5)$$

The proposed methodology involved selecting the parameter a_{ij} where i = 1, 2 and j = 1, 2, inaccordance with the required features, converting [A] matrices into node equations, and, finally, synthesizing the resulting node equations by physical circuits using CFOA and RC element.

2. Configuration of Oscillators

Most of the SRCOs are based on the tuning law given by eq. (6-7)

CO: R1= R3 (6)

$$\text{FO: } \omega_0 = \sqrt{\frac{1}{C1.C2.R2.R3}} \quad (7)$$

From equation (6), (7) condition of oscillation is controlled by R1 and that of frequency of oscillation by R3 respectively. However oscillators presented in this paper have been configured with a novel approach as of given by (6)& (7). This approach requires following steps-

1. Determining the elements of [A] matrices.
2. Converting [A] matrices in node equation.
3. Synthesizing the node equation into physical circuits using corresponding elements and CFOAs

Here we have discussed two circuits with different arrangement of elements of matrix [A], hence giving out different circuit configuration.

Circuit 1:-

Assuming the matrix [A] as

$$[A_1] = \begin{bmatrix} \frac{1}{C1.R3} & \frac{-1}{C1.R3} \\ \frac{1}{C2.R1} & \frac{-1}{C2.R2} \end{bmatrix}$$

Now from eqn. (4) and eqn. (5) we have condition of oscillation (CO) and FO are given by

$$\frac{1}{C1.R3} - \frac{1}{C2.R2} = 0 \quad (7)$$

$$\frac{1}{C1.R3} = \frac{1}{C2.R2} \quad (8)$$

$$\frac{R3}{R2} = \frac{C2}{C1} \quad (9)$$

Frequency is given by

$$\omega_0 = \sqrt{\frac{-1}{C1R3}.\frac{1}{C2R2} + \frac{1}{C1R3}.\frac{1}{C2R1}}$$

$$= \sqrt{\frac{1-\frac{R1}{R2}}{C1C2R1R3}} \quad (10)$$

$\frac{R1}{R2} < 1$ (From sensitivity calculation)

Characteristic eqn. for the above state variable equation can be stated as

$$S^2 - S\left(\frac{1}{C1R3} - \frac{1}{C2R2}\right) + \left(\frac{-1}{C1R3}.\frac{1}{C2R2} - \frac{1}{C1R3}.\frac{1}{C2R1}\right) = 0 \quad (11)$$

Nodal eqn. for the state variable equation can be stated as

$$C1\frac{dX1}{dt} = \left(\frac{X1-X2}{R3}\right) = \frac{X1}{R3} - \frac{X2}{R3} \quad (12)$$

$$C2\frac{dX2}{dt} = \left(\frac{X1}{R1} - \frac{X2}{R2}\right) \quad (13)$$

Here, X1 and X2 are the voltages across C1 and C2 $\frac{X1}{R3}, \frac{X2}{R3}, \frac{X1}{R1}, \frac{X2}{R2}$ are the branch currents. Realizing the corresponding circuit using CCII+ port characteristic Fig 2 gives the equivalent circuit diagram.

*Passive Sensitivity:*Frequency sensitivity$S_{\omega o}^{Rx}$ of the oscillator is defined as deflection produced in the operating frequency due to change in any of the passive components and is given as:

$$S_{wo}^{Rx} = \frac{d\omega o\ /\omega o}{dRx\ /Rx} \qquad (14)$$

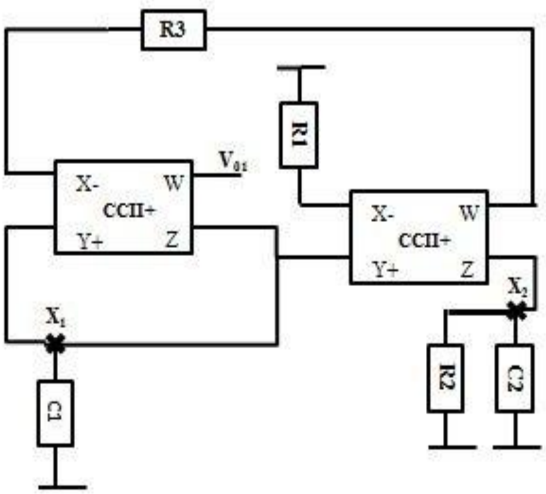

Fig 2: Circuit-1corresponding to eq. (12) and (13).

where, Rx is any passive component on which frequency depends.Frequency sensitivity of different component is found to be as follows

$$S_{\omega o}^{C1} = S_{\omega o}^{C2} = S_{\omega o}^{R3} = -\frac{1}{2} \qquad (15)$$

For R1, R2 sensitivity is found to be

$$S_{\omega o}^{R1} = \frac{-1}{2}\frac{1}{1-\frac{R1}{R2}} \qquad (16)$$

Hence for system to be stable -1 <$S_{\omega o}^{Rx} < 1$, therefor$\frac{R1}{R2} <$ for$\frac{R1}{R2} < 1$

Similarly for $S_{wo}^{R2} = -\frac{1}{2} . \frac{1}{1-\frac{R2}{R1}}$ (17)

If R1 and R2 are taken in such a way that $\frac{R2}{R1} = n$ then frequency stability factor is stated as:

$$S^F = -2\sqrt{\frac{n-1}{n}}(n-1) \qquad (18)$$

$= -2\sqrt{n}$; for n >> 1

Circuit 2:

In this circuit 5 passive elements are used. The state variable matrix is given as

$$[A_2] = \begin{bmatrix} \frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) & \frac{-1}{C1R3} \\ \frac{1}{C2}\left(\frac{1}{R3} - \frac{1}{R1}\right) & \frac{-1}{C2R3} \end{bmatrix} \qquad (19)$$

CE can be stated as

$$S^2 - \left(\frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) - \frac{1}{C2R3}\right) s + \frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) . \frac{-1}{C2R3} + \frac{1}{C1R3} . \frac{1}{C2}\left(\frac{1}{R3} - \frac{1}{R1}\right) = 0 \qquad (20)$$

$$S^2 - \left(\frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) - \frac{1}{C2R3}\right) s + \frac{1}{C1C2R3}\left(-\frac{1}{R2} + \frac{1}{R3} - \frac{1}{R3} - \frac{1}{R1}\right) = 0 \qquad (21)$$

From above eqn. (21) FO and CO can be stated as

$$\text{CO:}\left(\frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) - \frac{1}{C2.R3}\right) = 0 \qquad (22)$$

$$\frac{1}{C1}\left(\frac{1}{R2} - \frac{1}{R3}\right) = \frac{1}{C2R3} \qquad (23)$$

$$R3\left(\frac{1}{R2} - \frac{1}{R3}\right) = \frac{C1}{C2} \qquad (24)$$

$$\frac{R3}{R2} = 1 + \frac{C1}{C2} \qquad (25)$$

$$\text{FO:} \qquad \omega_0 = \sqrt{\frac{1}{C1.C2.R3}\left(-\frac{1}{R2} + \frac{1}{R1}\right)} \qquad (26)$$

$$\omega_0 = \sqrt{\frac{1-\frac{R1}{R2}}{C1.C2.R3.R1}} \qquad (27)$$

Passive sensitivity:

$$S_{\omega_0}^{C1} = S_{\omega_0}^{C2} = S_{\omega_0}^{R3} = -\frac{1}{2} \qquad (28)$$

As frequency of oscillation is given by same expression so sensitivity of different passive elements is same as that of found in circuit 1

$$S_{\omega_0}^{R2} = -\frac{1}{2} . \frac{1}{1-\frac{R2}{R1}} \qquad (29)$$

$$S_{\omega_0}^{R1} = \frac{-1}{2}\frac{1}{1-\frac{R1}{R2}} \qquad (30)$$

Hence for system to be stable -1 < $S_{\omega_0}^{Rx} < 1$, therefor $\frac{R1}{R2} <$ 1

Now taking $\frac{R3}{R2} = 2$ the stability of the circuit can be stated as

$$S^F = \sqrt{\frac{8(n-1)}{2n-1}} \quad (31)$$

$$= \sqrt{2n}\,; approx\ for\ n \gg 1$$

The node equation corresponding to state variable matrix can be stated as

$$C1\frac{dx1}{dt} = \frac{x1}{R2} - \left(\frac{x1+x2}{R3}\right) \quad (32)$$

$$C2\frac{dx2}{dt} = -\frac{x1}{R1} + \left(\frac{x1-x2}{R3}\right) \quad (33)$$

Realizing the circuit corresponding node equations with x1 and x2 as node voltage across capacitor C1 and C2, is shown in fig 3

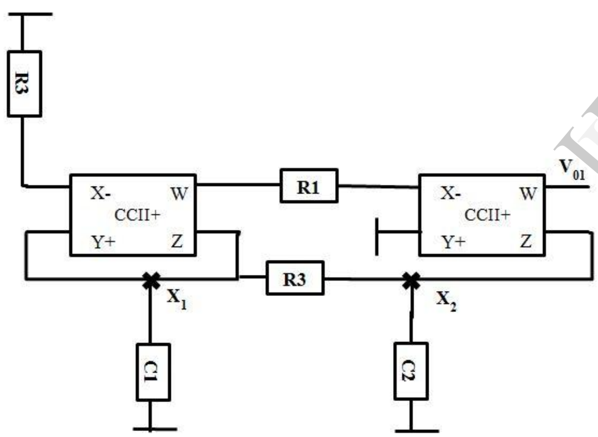

Fig 3: Circuit-2 corresponding to eq. (32) and (33).

3 Performance Analysis and Experimental Results

The above synthesized circuit have been realized using AD844 ICs model files in SPICE. The value of circuit elements used for each of the two circuits is listed in Table 1. The values are selected in accordance to eq. (9), (10) for circuit 1and eq. (25), (27) for circuit 2. The slight variation is for initialization of oscillation. Fig.4 gives the schematic generated in SPICE for circuit 1 for which generated sinusoidal output waveform is given by in Fig 5. To detect the harmonics generated Fourier transform for the generated signal is taken which indicates a very narrow spectrum given by Fig 6. Table 2 and 3 shows the normalized component, Fourier component and normalized phase component for circuit 1 and circuit2 respectively. Overall deviation from the main frequency component is given by THD and the DC component which are quit low as compared to conventional oscillators.

Table 1 : Values of elements used in simulation

PARAMETERS	**Values**	
	Circuit 1	**Circuit 2**
VDD	5V	5V
VSS	-5V	-5V
R1	3.2K	4K
R2	11.6K	4.9K
R3	10K	10K
RL	100k	100K
C1	1E-9 F	1nF
C2	1E-9 F	1Nf

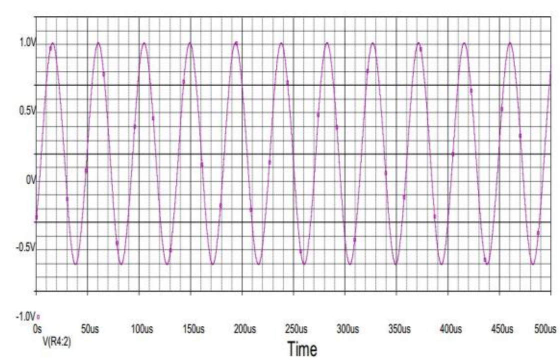

Fig 4: Sinusoidal waveform generated for circuit 1

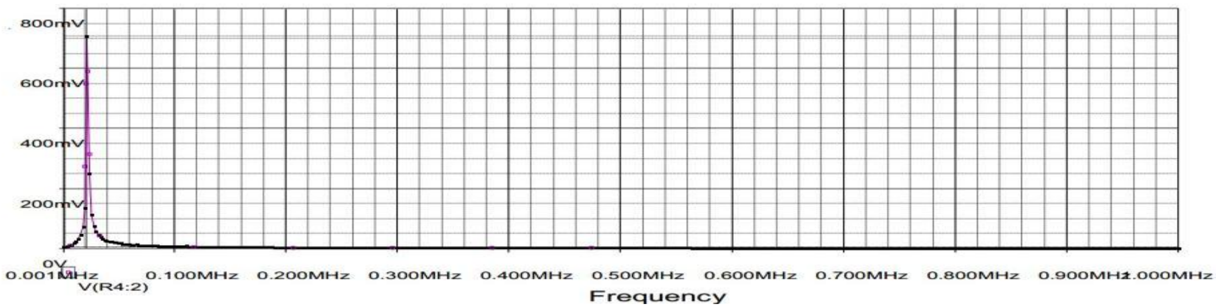

Fig : 5 FFT for Circuit-1

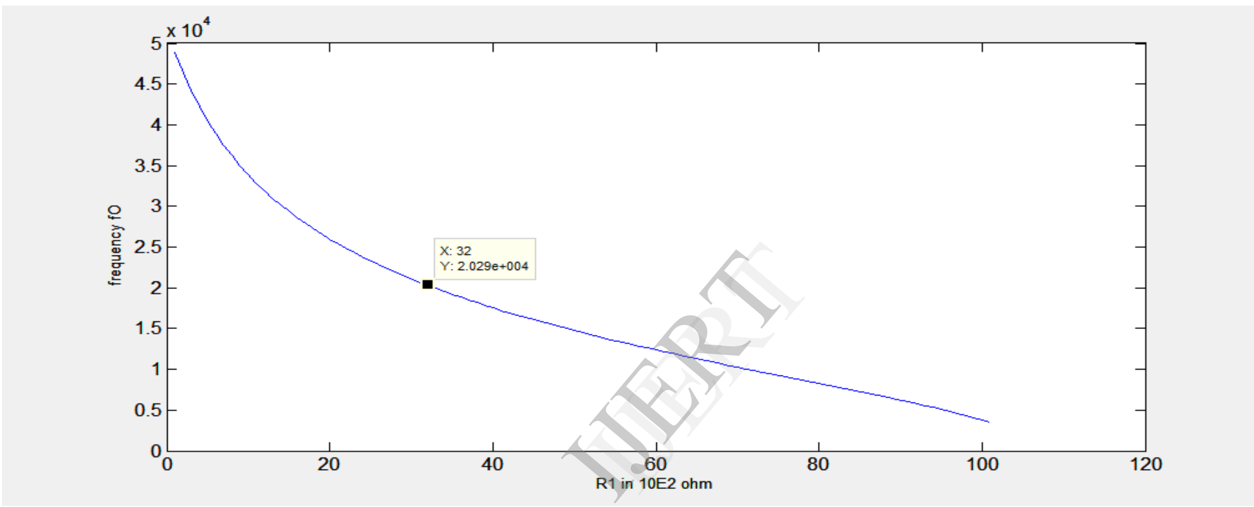

Fig :6 Variation of frequency f_0 with R1

Table 2: Fourier component for the transient response of circuit-1

HAR-MONICNO	FRE-QUENCY(HZ)	FOURIERCOM-PONENT	NORMALIZED-COMPONENT	PHASE(DEG)	NORMALIZED-PHASE (DEG)
1.	2.200E+04	7.969E-01	1.000E+00	4.743E+01	0.000E+00
2.	4.400E+04	1.876E-02	2.354E-02	-1.541E+02	-2.490E+02
3.	6.680E+04	2.926E-03	3.671E-03	-6.298E+01	-2.053E+02
4.	8.800E+04	8.019E-03	1.006E-02	-6.298E+01	-3.546E+02

Table 3: Fourier component for the transient response of circuit-2

HARMONICNO	FREQUENCY(HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZEDPHASE (DEG)
1.	1.033E+04	1.359E-03	1.000E+00	8.792E+01	0.000E+00
2.	2.066E+04	1.355E-03	9.964E-01	8.584E+01	-9.000E+01
3.	3.099E+04	1.346E-03	9.904E-01	8.377E+01	-1.800E+02
4.	4.132E+04	1.335E-03	9.820E-01	8.171E+01	-2.700E+02

4. Practical feasibility and significance

Both of the discussed oscillators contain a difference term in the expression for their FO which could be generalized to give eq. (34)

$$\omega_0 = \frac{\sqrt{1-\eta}}{RC} \tag{34}$$

Where η is the ratio of frequency controlling resistor and thus qualify to be used for generating very low frequency oscillations. These oscillators could be practically implemented using commercially available AD844 ICs which nearly accurate and stable frequency output as shown in fig 6 for circuit 1 the output of sinusoidal waveform from a Digital oscilloscope.

Table 4: Output parameters for circuit 1 and 2.

Output Parameters	**Circuit 1**	**Circuit 2**
Total Harmonic Distortion (THD)	2.59E-02	1.71E+00
DC component	1.59E-02	6.81E-04

5.Conclusion

Two new sinusoidal circuits employing CFOAs have been analysed each having grounded capacitor. The circuits have been derived by employing new tuning laws. Several others laws may be undertaken to realize sinusoidal oscillators. More over these circuits

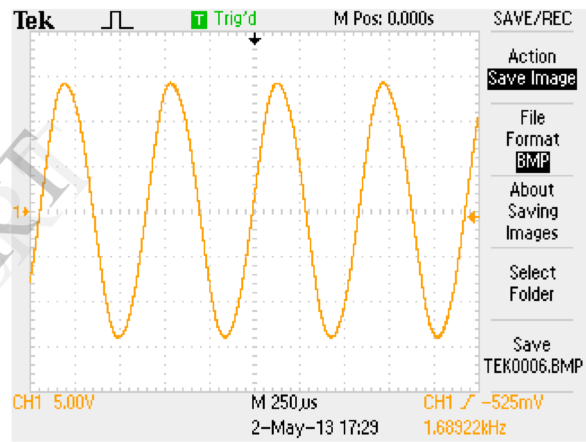

Fig 7: Sinusoidal Waveform from DSO for circuit-1

can be physically realized with bare minimum four passive elements and are suitable for is generation of VLF oscillation. Output waveform for such a circuit is shown in fig 7. It believed that aforementioned oscillators would found several applications in further to those discussed here.

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