IMPLEMENTATION OF THIRD ORDER QUADRATURE SINUSOIDAL OSCILLATOR EMPLOYING OTRAs

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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MASTER OF TECHNOLOGY
IN
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Submitted by:

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ABSTRACT

Circuit designers have found that conventional design methods based on voltage op-amps are no longer sufficient as signal processing extends over high frequencies. A new mode device known as the Operational Transresistance Amplifier (OTRA) has aroused the interest of analogue IC designers over the last few decades. In this thesis a third order quadrature sinusoidal oscillator using OTRAs is proposed. The proposed circuit consists of three capacitors, six resistors and three OTRAs. It provides high precision of frequency of oscillation. A single passive component can be used to control the frequency of oscillation and condition of oscillation can be controlled by setting the values of resistors. PSPICE simulation was used to test the proposed circuit's performance which used Taiwan semiconductor manufacturing company, TSMC's 250nm CMOS technology.

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LIST OF ABBREVIATIONS

Op Amp	Operational Amplifier
IC	Integrated Circuits
CMRR	Common Mode Rejection Ratio
CCCCTA	Current-controlled Current Conveyors Transconductance Amplifier
TOQSO	Third Order Quadrature Sinusoidal Oscillator
MCCFTA	Modified Current Regulated Current Follower
QO	Quadrature oscillators
PLL	Phase Locked Loop
QGA	Quantum genetic algorithm
COA	current operational amplifier
BW	Bandwidth
CDBA	Current differencing buffered amplifier
CFA	Current Feedback amplifier
CDTA	Current Difference Trans conductance Amplifier
OTA	Operational Transconductance Amplifier
OTRA	Operational Trans Resistance Amplifier
THD	Total Harmonic Distortion
DCVC	Differential Current Voltage Conveyor
CDBA	Current Differencing Buffered Amplifier
CCCDTA	Current-controlled Current Differencing Transconductance
MOS-C	Mosfet- Capacitor
CO	Condition of oscillation
FO	Frequency of oscillation

CHAPTER-1

INTRODUCTION

1.1 BACKGROUND

An amplifier is a type of electrical device that boosts the strength of a signal (a voltage or current that changes over time).This is a two-terminal electronic circuit that uses electrical energy from a power source to raise the amplitude of a signal applied to the input terminals and produce a signal with a correspondingly higher amplitude at the output. An amplifier's gain, or the ratio of power to output voltage, current, or input, is used to determine how much gain it provides. An amplifier is a circuit with a power gain greater than 1. The amplifier might be a stand-alone unit or a circuit embedded in another device. Modern electronic gadgets are built on the foundation of amplification, and amplifiers are found in practically all of them. Different classifications exist for amplifiers. The frequency of the amplified electrical signal, on the one hand. Audio amplifiers, for example, magnify signals below 20 kHz, RF amplifiers amplify frequencies in the high frequency range of 20 kHz to 300 GHz, and servo and instrumentation amplifiers are highly up to DC. It can operate at low frequencies. Amplifiers can also be categorized by their physical placement in the signal chain. The preamplifier can precede other signal processing stages.

Most current amplifiers include negative feedback to enhance bandwidth, reduce distortion, and adjust gain. A portion of the output is sent back and added to the input in anti phase in a negative feedback amplifier, effectively deducting it from the input. The major result is that the system's total gain is reduced. The undesired signal introduced by the amplifier, on the other hand. The distortion was communicated back to the user. These are added to and removed from the input in reverse order because they were not part of the original input. Negative feedback minimises nonlinearity, distortion, and other faults induced by the amplifier in this way. Negative feedback can minimise the inaccuracy to the point where the amplifier's response is almost insignificant. However, only if the amplifier gain is large and the following components totally define the system output power (closed loop power): Feedback loop. This method is particularly useful for operational amplifiers (op amps).

1.2 OPERATIONAL AMPLIFIER

A DC-coupled high-gain electronic voltage amplifier with a differential input and a single-ended output is referred to as an operational amplifier (op amp). The output potential of the op amp in this setup is generally 100,000 times larger than the potential difference between the input terminals (relative to circuit ground).Op amps were developed for use in analogue computers to execute mathematical operations in linear, non-linear, and frequency-dependent circuits. Operational amplifiers are used as building blocks for analogue circuits because of their flexibility. Op amps were developed for use in analogue computers to execute mathematical operations in linear, non-linear, and frequency-dependent circuits. Operational amplifiers are used as building blocks for analogue circuits because of their flexibility. A non-inverting input (+) with a voltage V_+ and an inverting input (-) with a voltage V_- make up the differential input of the amplifier and shown in fig.1.1. The op amp should ideally simply amplify the voltage difference between the two, also known as differential input voltage. The operational amplifier's output voltage V_{out} is calculated using the equation (1.1) below.

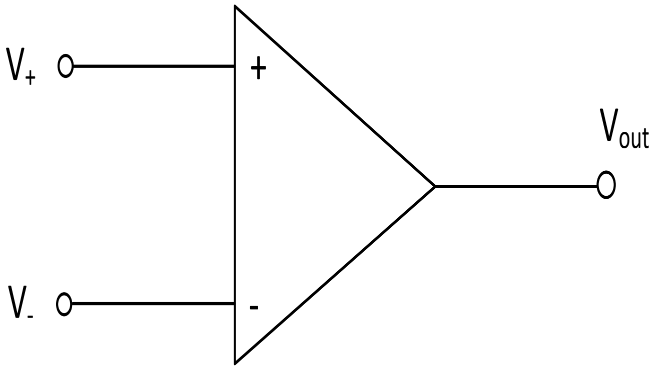

Fig.1.1Operational Amplifier

$$V_{out} = A_{ol}(V_+ - V_-) \qquad (1.1)$$

Where A_{ol} refers to open loop gain of amplifier

A differential amplifier that is used for operational purposes is known as an operational amplifier. Fully differential amplifiers (like op amps but with two outputs), instrumentation amplifiers (typically consisting of three opamps), isolation amplifiers (like the instrumentation amplifier), and negative feedback amplifiers are all examples of differential amplifiers (usually consisting of one or more op amps and a resistance feedback network). Figure 1.2 depicts the internal construction of the op-amp.

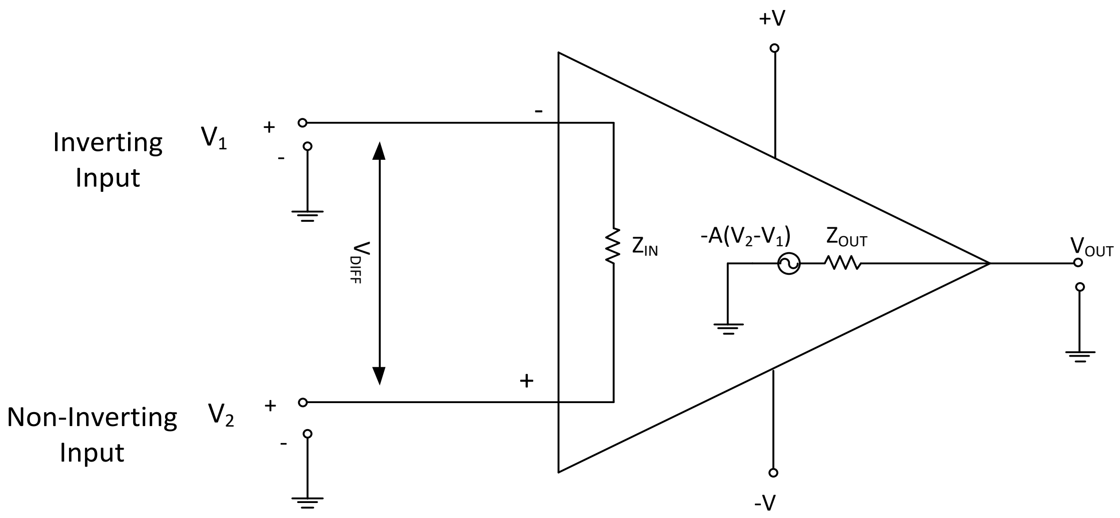

Fig.1.2 Schematic of operational amplifier

Using op amps has several advantages. Op amps are widely accessible, generally in the form of ICs, and come in a broad range of power levels to suit any application. Operational amplifiers are key components in many analogue applications, such as filter design, voltage buffers, and comparator circuits, due to their wide range of uses.

Most companies provide simulation support, such as the PSPICE model, which allows designers to validate op amp designs before creating the final product.

Op amps are analogue circuits which defines that they require a designer who understands the fundamentals of analogue, such as load, frequency response, and stability. It's not unusual to create something that appears to be a basic op amp circuit, only to have it switch on and oscillate.

There are some important parameters mentioned earlier, and the designer needs to understand how these parameters are reflected in the design. This means that designers usually need to have moderate to advanced analog design experience.

Various op amp circuits are present, all having different capabilities. A few of the most prevalent topologies are listed here.

1.2.1 Voltage Follower

A voltage follower, as depicted in Figure 4, is the simplest basic op amp circuit. This circuit is a handy buffer since it requires no extra components and has a high input impedance and a low output impedance. Changes in the input yield comparable changes in the output voltage since the input and output voltages are the same.

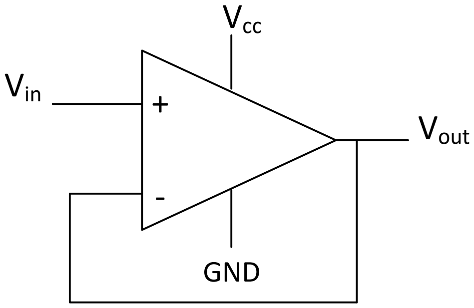

Fig.1.3 Voltage follower

$$V_{out} = V_{in} \tag{1.2}$$

1.2.2 Inverting Amplifier

The op amp pushes the negative terminal to the positive terminal in an inverting amplifier. In most cases, positive terminals are grounded. As a result, the Vin / R1 ratio determines the input current.

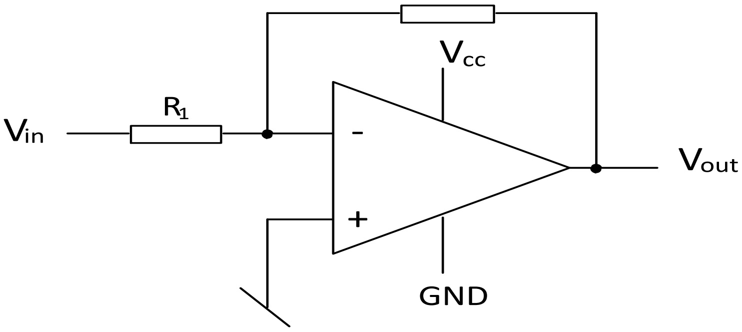

Fig.1.4 Inverting Amplifier

The equation of V_{out} comes out to be:

$$V_{out} = -\frac{R_2}{R_1} V_{in} \tag{1.3}$$

1.2.3 Non Inverting Amplifier

The inverting terminal voltage is forced to equal the input voltage by op amp. Current flows through the feedback resistor as a result of this is called non-inverting because both are in phase (output voltage and the input voltage).

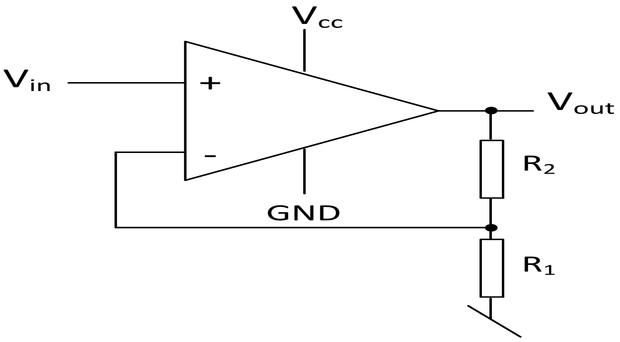

Fig.1.5 Non Inverting Amplifier

The equation of V_{out} comes out to be:

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in} \tag{1.4}$$

As signal processing spreads beyond high frequencies, circuit designers have realized that traditional voltage op amp-based design methods are no longer sufficient. The bandwidth of traditional amplifiers is commonly thought to be equal to the gain of a closed power supply. Current mode circuits have sparked interest as a possible solution to this problem. To increase flexibility and deliver steady bandwidth for profit, these circuits employ current processing techniques. Over the last decade, analogue IC designers have been intrigued by a new mode device known as the Operational Transresistance Amplifier (OTRA).

1.3 OPERATIONAL TRANSRESISTANCE AMPLIFIER

An operational transresistance amplifier is a differential current controlled voltage source with preferably zero input and output impedance. The OTRA is a three-terminal device with a high current input voltage output and a high gain current input voltage. The input and output signals must be transformed to voltage utilizing Transresistance to make current mode circuits compatible with voltage processing circuits. As the active element, OTRA takes use of the current at terminals of input and may directly drive existing voltage mode signal processing circuits, eliminating the need for extra circuitry and power consumption. The following matrix characterizes the relationship between OTRA's input and output terminals.

The transformer resistance gain Rm approaches infinity in optimal operation, ensuring that the input currents are equal. Low input and output impedance might be regarded OTRA's key benefit, regardless of device gain bandwidth.

Commercially available OTRA names include Current Differential Amplifier and Norton Amplifier. There is no internal grounding at the input terminals in these commercial systems, and input current can only travel in one way.

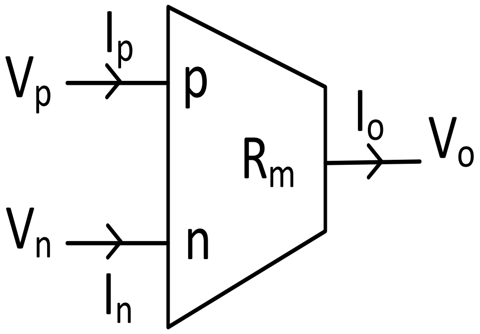

Fig. 1.6 Symbol of OTRA

OTRA is defined by following determinant:

$$\begin{bmatrix} V_p \\ V_n \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_o \end{bmatrix}$$

$V_p = V_n = 0$ (1.5)

$V_o = I_pR_m - I_nR_m$ (1.6)

Where R_m is transresistance gain

The block diagram of the Operational Transresistance Amplifier shown in Fig. 1.1. Since the terminal of input is actually grounded, the circuit becomes insensitive to most of the stray capacitance.

1.4 Applications of OTRA

There are several application of OTRA circuit as OTRA is commonly used in realisation of signal processing. Few topologies are explained below:

1.4.1 Integrator

The basic integrator is shown in fig.1.7 which uses a capacitor, two mosfets and a single OTRA[50]. Basically, it accumulates the input quantity over a defined time to produce a representative output.

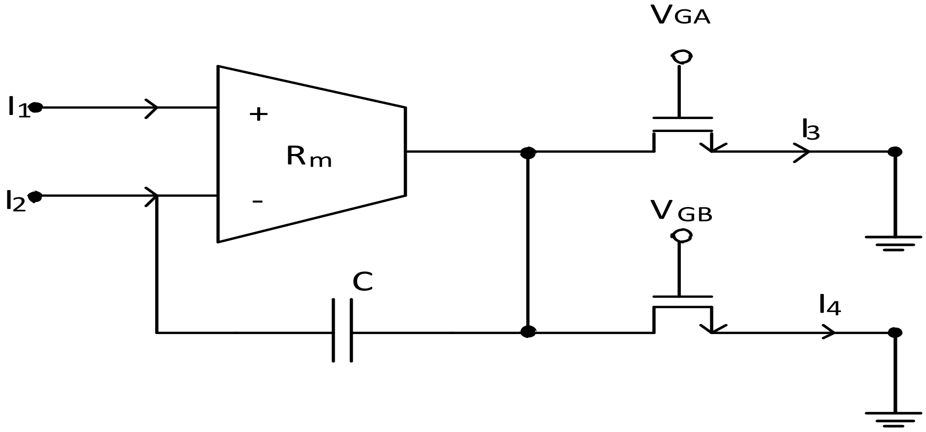

Fig.1.7 OTRA based Integrator

The relationship between output currents I_3, I_4 and input currents I_1, I_2 of integrator is :

$$I_3(s) - I_4(s) = \frac{2K}{sC}(V_{GA} - V_{GB})(I_1(s) - I_2(s)) \quad (1.7)$$

1.4.2 Differentiator

The basic differentiator is shown in fig.1.8 which uses a capacitor, two mosfets and a single OTRA[50]. The differentiator circuit is essentially a high pass filter. In ideal cases, a differentiator reverses the effect of an integrator on a waveform and conversely.

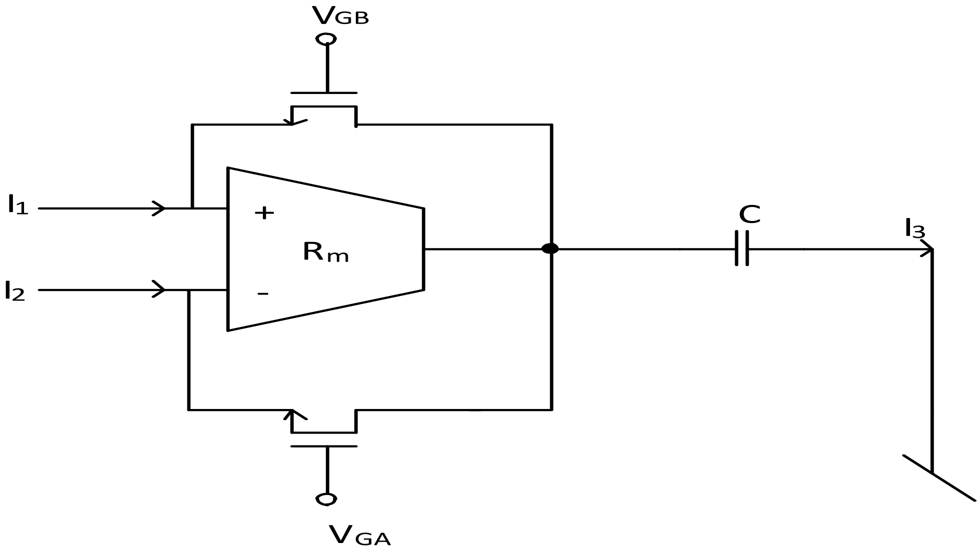

Fig.1.8 OTRA based Differentiator

The relationship between output current I_3, and input currents I_1, I_2 of differentiator is :

$$I_3(s) = \frac{sC}{2K(V_{GA}-V_{GB})}(\mathrm{I}_1(\mathrm{s}) - \mathrm{I}_2(\mathrm{s})) \tag{1.8}$$

1.4.3 First order filter

The first order All pass filter using OTRA[51] is shown in fig.1.9. All-pass filters are one of the most important building blocks of many analog signal processing applications, and therefore have received much attention. They are generally used for introducing a frequency dependent delay while keeping the amplitude of the input signal constant over the desired frequency range.

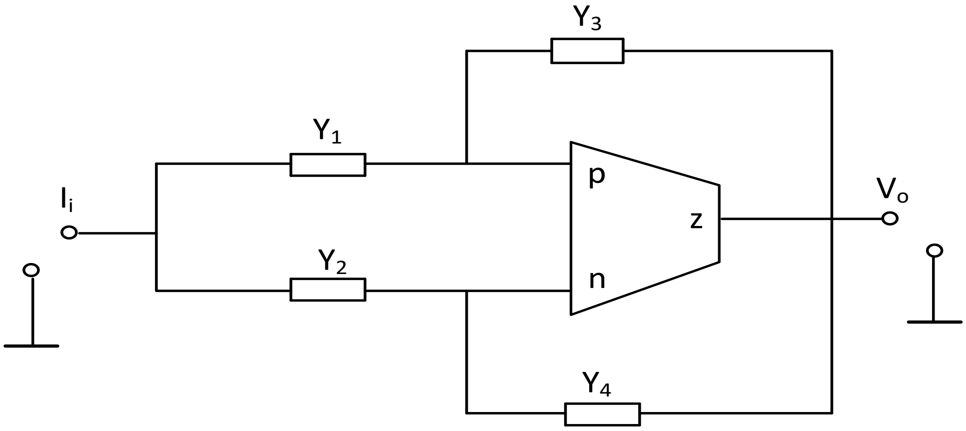

Fig.1.9. First order All pass filter using OTRA

The transimpedance transfer function is as follows:

$$\frac{V_o}{I_i} = \frac{1}{Y_4 - Y_3}\frac{Y_1 - Y_2}{Y_1 + Y_2} \tag{1.9}$$

1.4.4 Second order filter

The second order Universal filter using OTRA[52] is shown in fig.1.10. By selecting the proper values of V_1, V_2, V_3, V_4 and V_5, Universal filter can be used as low pass, high pass, band pass, band reject and all pass filter.

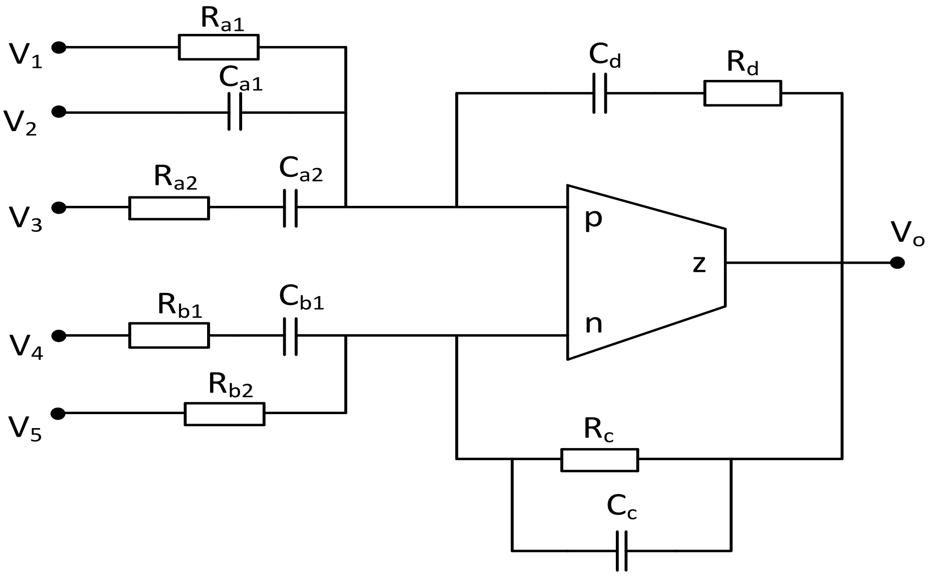

Fig.1.10. Second order Universal filter

The corresponding transfer function can be written as:

$$\frac{N(s)}{D(s)}=\frac{\frac{1}{R_{a1}}V_1+C_{a1}sV_2+\frac{C_{a2}s}{R_{a2}C_{a2}s+1}V_3-\frac{C_{b1}s}{R_{b1}C_{b1}s+1}V_4-\frac{1}{R_{b2}}V_5}{\frac{1}{R_c}+C_cs-\frac{C_ds}{R_dC_ds+1}} \tag{1.10}$$

1.5 Outline of the work presented in the dissertation

In this dissertation, chapter 1 covers the basic concepts of operational amplifier. Operational Amplifier and it's common topologies has been discussed in detail. Operational transresistance amplifier (OTRA) is explained with its symbol, matrix, equation and schematic diagram. Some of the important applications of OTRA is also shown in this chapter. Second chapter covers the literature survey of third order sinusoidal oscillator realised with modern active building blocks. Barkhausen criterion is also explained with wien bridge oscillator and RC phase shift oscillator. After that Oscillators are discussed in detail with quadrature oscillator and higher order oscillators. In third chapter, CMOS implementation of OTRA is explained with details of each mosfet. The dc characterstics of OTRA is also plotted in this section. The circuit of third order quadrature sinusoidal oscillator is proposed. In this section characteristic equation, FO and CO are calculated. This section includes non-ideal analysis as well. Then, the result and simulation of 3rd order circuit is shown. The frequency analysis and the simulated quadrature output waveform which can also be called transient output of the proposed circuit is shown in this chapter. In last and the final chapter conclusion and future scope are mentioned.

CHAPTER-2

LITERATURE SURVEY

2.1 Introduction

An oscillator is a circuit that produces a series of alternating waveforms that repeat without input. An oscillator is a circuit that generates sinusoidal waveforms with a set amplitude and frequency using a positive feedback amplifier. In electrical and electronic instruments, it is the primary source of power. Even in the absence of any input, the amplifier with positive feedback can generate a sinusoidal signal.

The term "positive feedback" refers to the addition of a portion of the output signal to the input signal voltage. The amplifier circuit allows this to pass through. It is passed through the amplifier with the input signal from the source. The amplifier does nothing but combine the signal from the feedback path with the signal from the input. As a result, constant oscillations are formed, and eventually the oscillator circuit generates waveforms without any input signal.

Oscillators are primarily used for sine wave sources in electronic measurements[49]. Oscillators can generate a wide range of frequencies (several Hz to several GHz), depending on the requirements of the application. Oscillators are typically positive feedback amplifiers. The oscillator gain is 1 or greater. Capacitors, inductors, or both are used as invalid components in the oscillator feedback path. In addition to these invalid components, op amps or bipolar transistors are used as amplification devices.

Oscillators are essentially amplifier circuits with positive or regenerative feedback, which implies that a portion of the output signal is returned back into the input. By correcting for circuit losses, the back-fed in-phase signal is held responsible for maintaining the oscillations. Due to the electrical noise existing in the system, oscillations will commence immediately the power supply is turned on. As the noise signal travels around the loop, it gets louder and louder until it converges to a single frequency sine wave.

2.1.1 The Oscillator Feedback Loop

The basic structure of a sinusoidal oscillator consists of an amplifier and a frequency selective network connected in a positive feedback loop, such as that shown in block diagram form in Fig.2.1. It is the use of positive feedback that results in a feedback amplifier having closed-loop gain A_f greater than unity and satisfies the phase condition. In a system assuming, V_{in}, and V_{out} as the input and output voltages respectively.

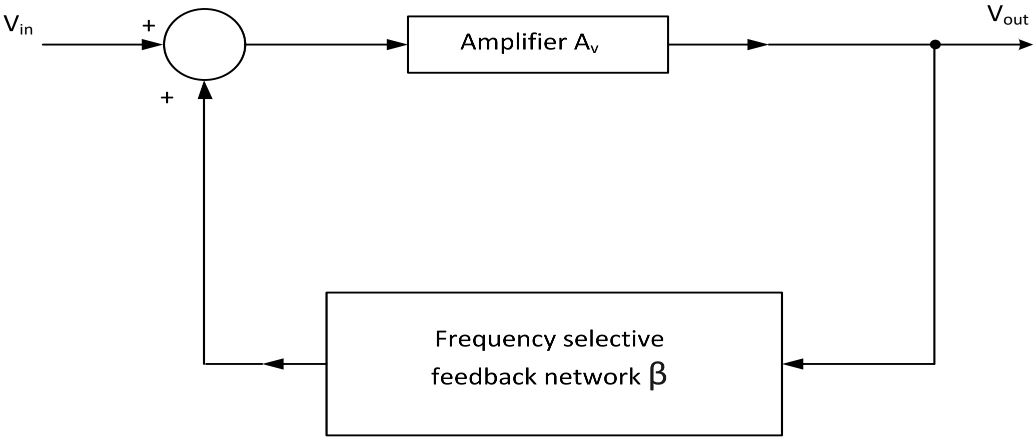

Fig.2.1 The basic structure of sinusoidal oscillator

Without feedback or open gain loop gain, then

$$A_v = \frac{V_{out}}{V_{in}} \tag{2.1}$$

Hence, $V_{out} = A_v V_{in}$ (2.2)

Taking the forward path gain of the system as A and β as feedback factor; with feedback, the output voltage of the system:

$$V_{out} = A_v(V_{in} + \beta V_{out}) \tag{2.3}$$

$$V_{out} = \frac{A_v V_{in}}{1 - A_v \beta} \tag{2.4}$$

Divide by V_{in}

$$\frac{\mathrm{V_{out}}}{V_{in}} = \frac{A_v}{1-A_v\square} \tag{2.5}$$

Therefore,

$$A_f = \frac{\mathrm{V_{out}}}{V_{in}} = \frac{A_v}{1-A_v\square} \tag{2.6}$$

Where A_f is the closed loop gain

2.1.2 Barkhausen Criterion

Conditions which are required to be satisfied to operate the circuit as an oscillator are called as “Barkhausen criterion” for sustained oscillations. The Barkhausen criteria should be satisfied by an amplifier with positive feedback to ensure the sustained oscillations. For an oscillation circuit, there is no input signal “Vs”, hence the feedback signal V_f itself should be sufficient to maintain the oscillations.

The Barkhausen criterion states that:

- The loop gain is equal to unity in absolute magnitude, that is, $|\beta A| = 1$ and
- The phase shift around the loop is zero or an integer multiple of 2π radian (180°) i.e.

$\angle \beta A=0$ or $2n\pi$

The product β A is called as the “loop gain”.

Some of the famous oscillator circuits utilizing op-amps and RC networks are as follows:

2.1.3 Wien- Bridge Oscillator

A Wien bridge oscillator is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The bridge comprises four resistors and two capacitors. The oscillator can also be viewed as a positive gain amplifier combined with a bandpass filter that provides positive feedback.

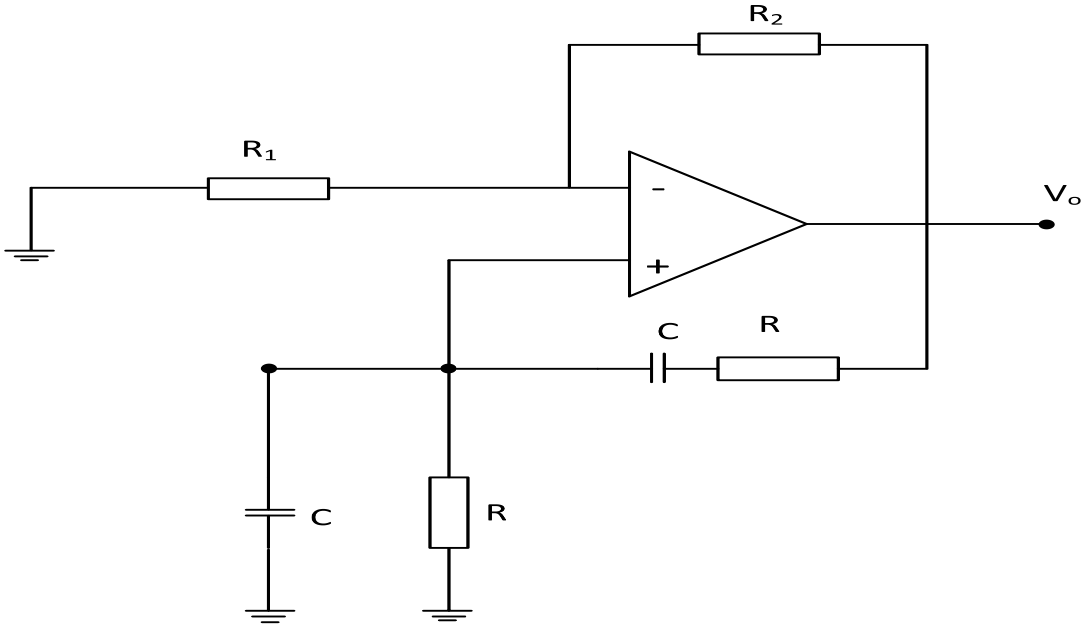

Fig.2.2 Wien bridge oscillator

The loop gain will be a real number (that is, the phase will be zero) at one frequency given by:

$$\omega_o = \frac{1}{CR} \tag{2.7}$$

To obtain sustained oscillations at this frequency, one should set the magnitude of the loop gain to unity. This can be achieved by selecting

$$R_2 = 2R_1 \tag{2.8}$$

2.1.4 RC Phase Shift Oscillator

RC phase-shift oscillators use resistor capacitor (RC) network to provide the phase-shift required by the feedback signal. They have excellent frequency stability and can yield a pure sine wave for a wide range of loads. Ideally a simple RC network is expected to have an output which leads the input by 90°.14 However, in reality, the phase-difference will be less than this as the capacitor used in the circuit cannot be ideal. Mathematically the phase angle of the RC network is expressed as

$$\Phi = \tan -1 \left(\frac{X_c}{R}\right) \tag{2.9}$$

Where, $X_c = \frac{1}{2\pi FC}$ (2.10)

X_C is the reactance of the capacitor C and R is the resistor.

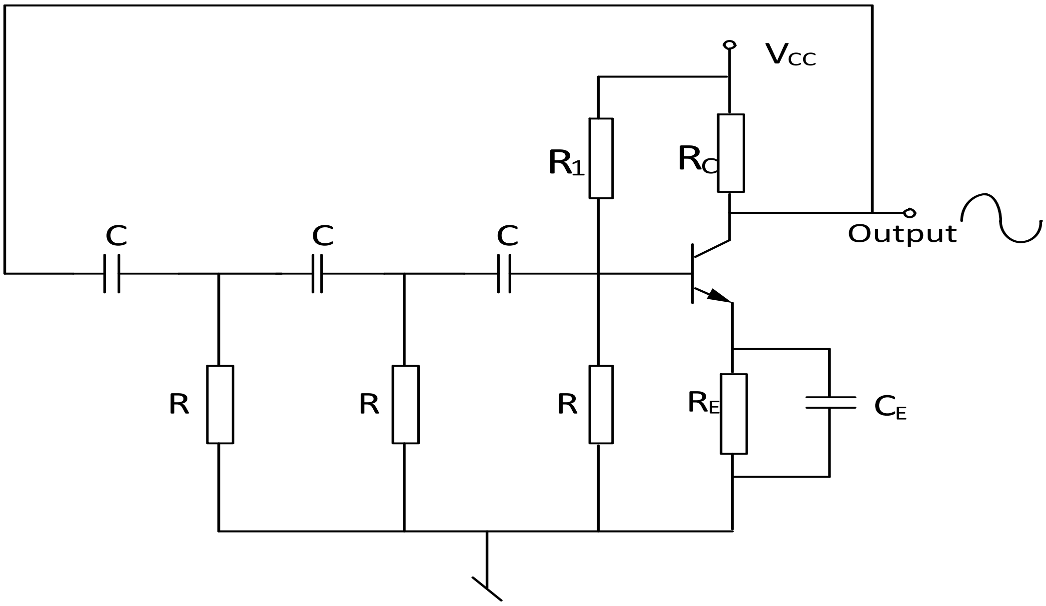

Fig.2.3 (a) RC phase shift oscillator using npn transistor

In oscillators, these kind of RC phase-shift networks, each offering a definite phase shift can be cascaded so as to satisfy the phase-shift condition led by the Barkhausen Criterion.

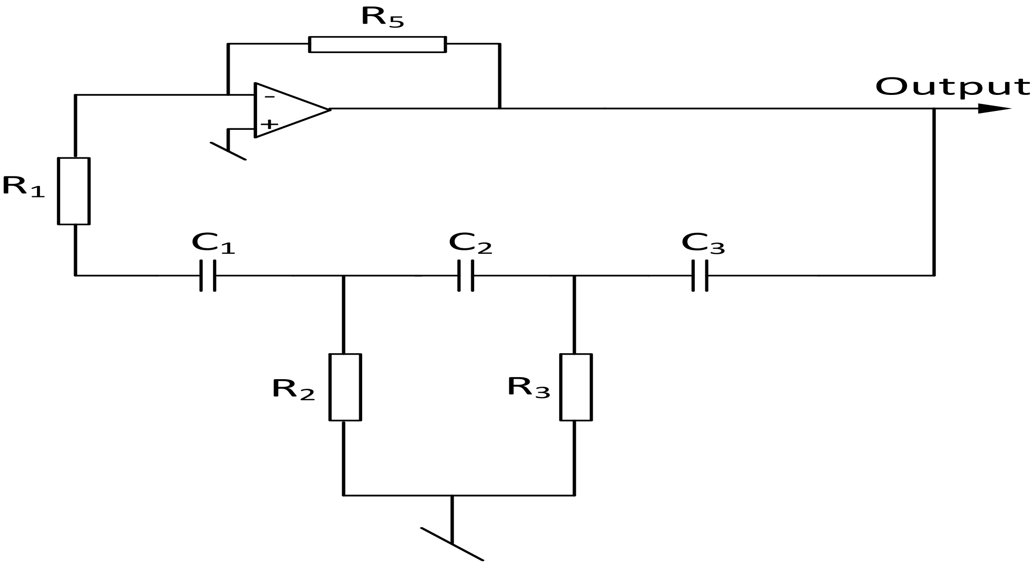

Fig.2.3 (b) RC phase shift oscillator using op-amp

One such example is the case in which RC phase-shift oscillator is formed by cascading three RC phase-shift networks, each offering a phase-shift of 60°, as shown by Figure Here the collector resistor RC limits the collector current of the transistor, resistors R1 and R (nearest to the transistor) form the voltage divider network while the emitter resistor RE improves the stability. Next, the capacitors CE and Co are the emitter bypass capacitor and the output DC decoupling capacitor, respectively. Further, the circuit also shows three RC networks employed in the feedback path. This arrangement causes the output waveform to shift by 180° during its course of travel from output terminal to the base of the transistor. Next, this signal will be shifted again by 180° by the transistor in the circuit due to the fact that the phase-difference between the input and the output will be 180° in the case of common emitter configuration. This makes the net phase difference to be 360°, satisfying the phase-difference condition.

2.2 Quadrature Oscillator

The quadrature oscillator is another sort of phase shift oscillator. The quadrature oscillator is different in that it uses an op amp integrator to get a whole 90° phase shift from a single RC segment while keeping the output voltage usable. Because of the 90° phase shift, we only need two op amps to produce both sine and cosine wave outputs. Fig.2.5 shows a practical quadrature oscillator. Amplifier 1 is connected as an inverting Miller integrator with a limiter in the feedback for amplitude control. Amplifier 2 is connected as non inverting integrator .

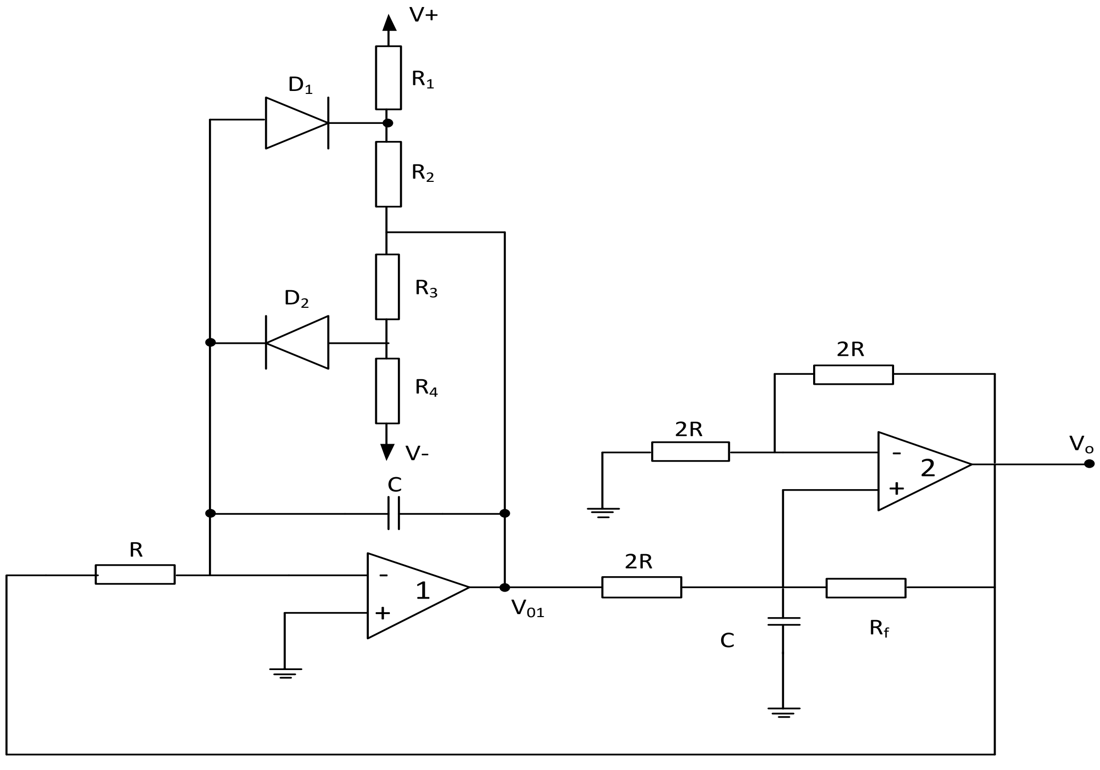

Fig.2.4 Quadrature Oscillator

This connection is helpful for communications that need both in phase and orthogonal components, such as the quadrature mixer and single sideband generator [44]. Instrumentation applications such as vector generators and selective voltmeters are also detected by QO [45]. Higher-order networks outperform lower-order circuits in terms of accuracy, frequency responsiveness, and distortion [46,47]. This link is mathematically expressed in [48].

2.2.2 Third order Quadrature Oscillator

Order of any oscillator circuit can be determined by looking at the reactive elements present in circuit and characteristic equation can be used to verify the order of that oscillator circuit. Basically, in case of third order sinusoidal oscillator, three reactive elements(i.e. capacitor or inductor) will be present in that oscillator circuit and can be further verified by calculating the characteristic equation of the circuit.

In comparison to lower order oscillators, third order oscillators provides improved frequency response, precision and efficiency. The quality of the sinusoidal wave improves as the order increases, and total harmonic distortion (THD) diminishes.

There is no harmonic distortion in a pure sine wave voltage or current since it is a signal with only one frequency. High frequency components are present in periodic voltages or currents that are not pure sine and cosine, contributing to the signal's harmonic distortion. For the design of commercial and industrial power systems, power quality is critical. The power supply should ideally be a distortion-free sinusoidal waveform. If the voltage-current waveform distorts from the ideal shape, it is called harmonic distortion.

Since this work deals with realisation of third order sinusoidal oscillators, in the following, we have presented a brief overview of some of the important works dealing with the realization of third order quadrature sinusoidal oscillators realized with modern active building blocks.

2.3 Third Order Sinusoidal Oscillators realised with modern active building blocks

In [1] a third order current-mode quadrature oscillator with active components that are current controlled current conveyor transconductance amplifiers (CCCCTAs) was proposed. The circuit, which is ideal for IC design, comprises of 2 CCCCTA and 2 grounding capacitors. In [2], a third current-mode quadrature oscillator was proposed which is realised from a second order low pass filter and lossless integrator and uses current controlled current conveyor transconductance amplifier (CCCCTA) and operational transconductance amplifier (OTA). In [3] a current/voltage-mode third-order quadrature oscillator was proposed using current differencing transconductance amplifiers with grounding capacitors.

In [4] a current-mode third-order quadrature oscillator based on current differencing transconductance amplifiers (CDTAs) was proposed and only grounding capacitors were used. In [5] a third-order quadrature sinusoidal oscillator (TOQSO) using two voltage differencing inverting buffered amplifiers, three grounded capacitors, and a resistor was presented.

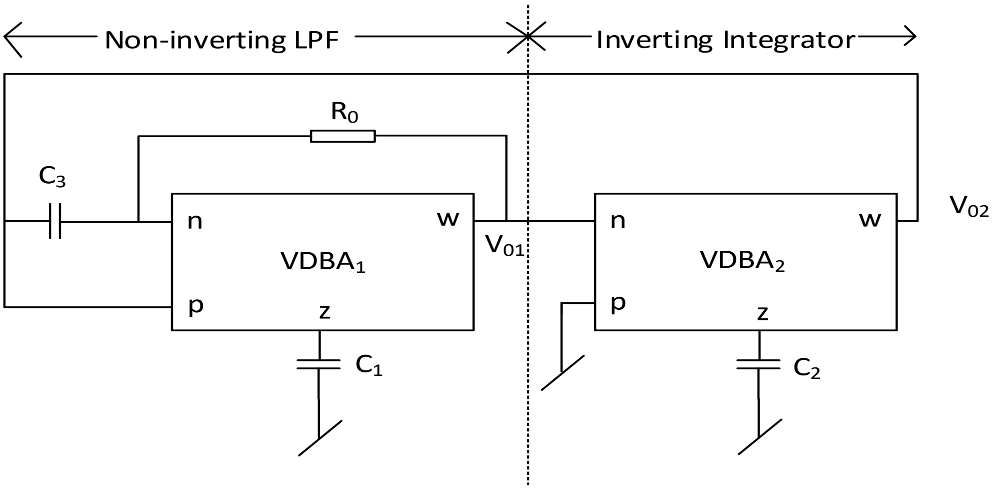

Fig. 2.5 Third order quadrature sinusoidal oscillator proposed in [5]

In [6] a novel mixed-mode third order quadrature oscillator based on a modified current-controlled current follower transconductance amplifier (MCCFTA) was proposed with four quadrature current outputs and two voltage outputs on a single architecture. In [7] a novel current-controlled current mode third-order quadrature oscillator was proposed. Only one

Modified Current Regulated Current Follower (MCCCFTA) and three grounded capacitors are used in the proposed circuit, making it ideal for integration. In [8] four new very-low-frequency third-order quadrature sinusoidal oscillators based on CFOAs, each with independent condition and frequency control was presented.

In [9] a novel third-order quadrature oscillator that can give four quadrature current outputs and two quadrature voltage outputs was presented.

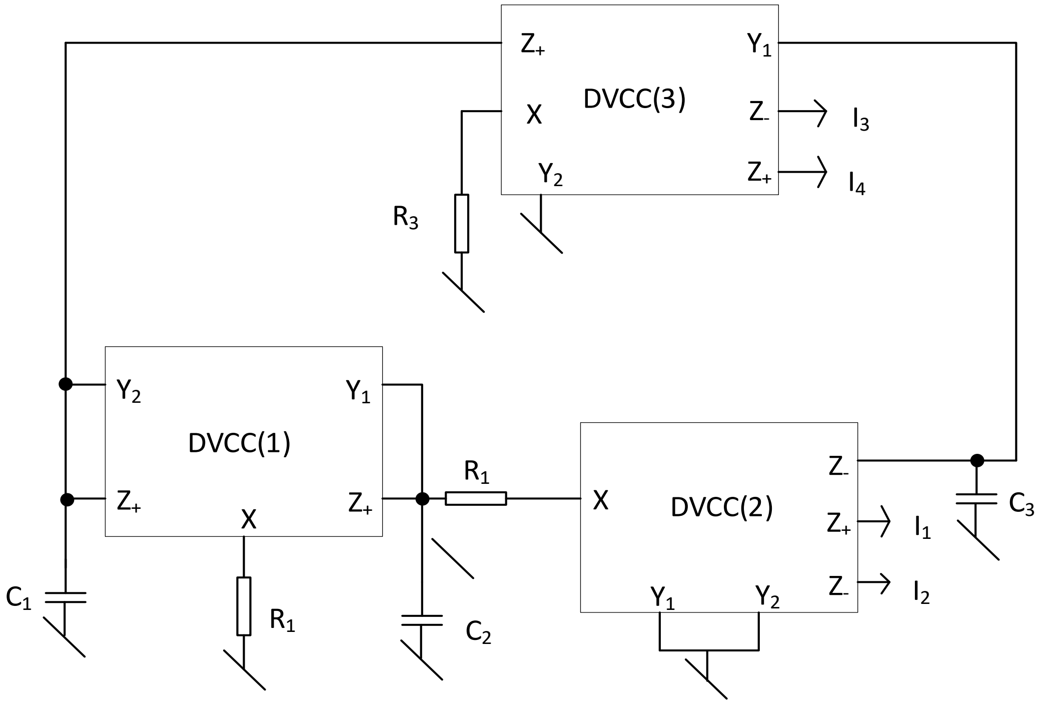

Fig. 2.4 New third order quadrature oscillator proposed in [9]

In [10], current mode blocks are used to create an electrically controllable third-order sinusoidal oscillator. This circuit has strong high-frequency performance and wide-range frequency tuning. In [11] a generalized system of third-order autonomous Duffing–Holmes system and particular attention is paid to the effect created by the model of symmetric and asymmetric nonlinearities on the dynamics of the system was proposed. The latter simulation in PSpice confirmed the numerical results. In [12] a novel VOC for three phase dc/ac inverters and analysed the non linear dynamical equations and simplified its nonlinear current source was presented.

In [13], two multiple output current controlled current conveyor transconductance amplifiers (MO-CCCCTAs) and three grounded capacitors were utilised to realise a resistorless third-order quadrature oscillator. Industry needs for phase shift modulated signals, amplifiers, and modulated signals are met by the proposed generator. In [14] a unique Duffing Holmes type autonomous chaotic with two extra linear feedback subcircuits and no external periodic driving was proposed. The novel circuit is based on a nonlinear resonator and a negative feedback linear damping loop. In [15] a current- and voltage-mode third order quadrature oscillator circuit was proposed using current and voltage conveyors. The redesigned circuit includes oscillation frequency control that is independent of the generating circumstances, the use of solely grounded passive parts, and quadrature current and voltage outputs.

In [16] a new electrically adjustable current-mode third-order quadrature oscillator based on voltage differencing transconductance amplifier (VDTA) was presented, which has an advantage for integrated circuit implementation. At the high output impedance terminals, this circuit gives two current outputs that are 90° out of phase. In [17], one completely differential second-generation current conveyor (FDCCII), three capacitors, and three resistors are used to create a mixed-mode third-order quadrature sinusoidal oscillator. In a single topology, this circuit offers two quadrature voltage outputs and two quadrature current outputs.

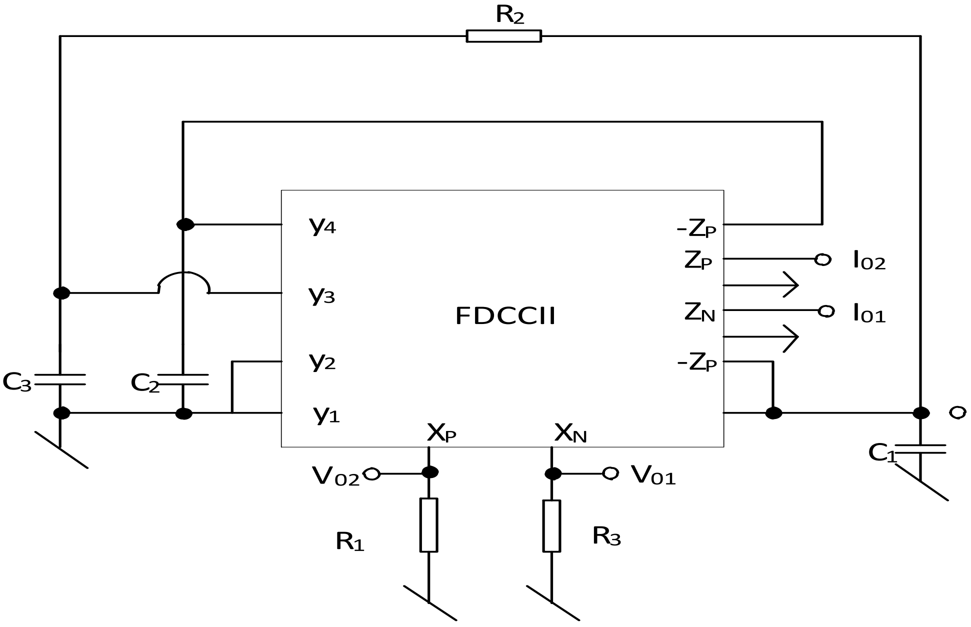

Fig. 2.5 Mixed mode third order quadrature sinusoidal oscillator proposed in [17]

In [18], a third-order Quadrature Sinusoidal Oscillator (QSO) was proposed using a Current Differencing Buffered Amplifier (CDBA). The prototype circuit's implementation perspective corresponds to a certain type of filter, such as low-pass (LP), high-pass (HP), and all-pass (AP) filters with closed-loop integrators/differentiators. In [19] several kinds of inaccuracy impact and the tracking performance of a phase-locked loop (PLL) was presented. Oscillator phase noise, in addition to thermal noise and dynamic voltage errors, can cause substantial phase jitter, which impairs tracking performance. In [20] a design for a 3rd-order oscillator was presented which is based on the principle of filtering. By changing the bias current to the oscillation frequency, this circuit may be instantly controlled throughout a broad range of frequencies, indicating the proposed circuit's appropriateness for high-frequency applications.

In [21] Numerical studies were performed to solve third-order van der Pol oscillator classes for differential equations related to nonlinearities for two parameters based on rigid and non-stiff conditions.

In [22] a third-order piecewise linear dynamics with the two regions of a chaotic Kolpitz oscillator was presented which can be mapped to the Chua oscillator with the asymmetric nonlinearities. In [23] Measured zero position of third-order sensitivity to two-photon resonance (6'S-7'S) summation of frequencies in atomic mercury. The uncertainty of the 7SnP oscillator strength is typically 3550%. The third-order absolute sensitivity is determined for energies less than 83,000 cm -1 , typically with an error of 20-30%.

In [24], a free-dissipative third-order nonlinear oscillator was presented. The evolution of contraction and shift numerical state is a number contraction of both strong and weak, major contraction of vacuum fluctuations, and the creation of superposition states. In [25] the branching point of the limiting cycle for the triter in a cubic piecewise linear forced oscillator was proposed. It is not possible to create a triter from a third-order independent oscillator. The dynamic model shows the minimum dimension of the triter. We employ a two-torus, third-order piecewise linear oscillator and apply a periodic perturbation to it. In [26] a current-controlled mixed mode 3rd-order quadrature oscillator was presented. One Modified Current Controlled Conductive Amplifier (MCCCTA) and 3 grounded capacitors are used in the proposed construction to provide 2 quadrature voltage outputs and 4 quadrature current outputs.

In [27] the development of the first offline third-order linear time-varying circuit was proposed utilising memristors in conventional oscillators to enhance parameter generation. Although the output oscillates at a constant rate, the linear character of a typical generator changes with time.

In [28], a unique third-order quadrature oscillator was presented. Due to the high impedance of the current output terminal, it may be connected straight to the next stage without the use of a buffer circuit.

In [29] a third-order sinusoidal oscillator was presented by using VDTA with a grounded capacitor. Two VDTAs and three grounded capacitors make up the suggested circuit. The sinusoidal output signal has two modes: voltage and current.

In [30], a quadrature current oscillator was proposed using active devices differential current differential pipeline (DDCC) and differential transconductance amplifier (VDTA). Oscillators have a high output impedance that can be easily cascaded or driven into external loads without buffering devices.

In [31], the electrical structure and optical characteristics of single-electron quantum dots (QDs) with and without impurities at the centre were investigated using a spherical symmetric limiting potential of limited depth. Quantum genetic algorithm (QGA) and Hartree-Fock Rutan (HFR) methods were used to determine QD energy and state function eigen values.

In [32] a new multifunction filter was presented using one current operational amplifier (COA) along a MOSC implementation & a third-order sine oscillator as an application and also included pilot study using commercially available 844 CE as Certificate of Authenticity subsystem to test the proposed topology to work.

In [33] a systematic implementation of a third-order quadrature oscillator was presented using a non-inverting low-pass filter with voltage mode and an inverting lossless feedback integrator with voltage mode. New circuit allows the simultaneous use of three variable amplitude current outputs.

In [39], a mixed-mode biquad filter configuration based on a transconductance operational amplifier (OTA) using four OTAs was proposed. The circuit uses a standard number of grounded capacitors (02), which are ideal for making integrated circuits. The proposed biquad structure has orthogonal configurability of pole frequency (ω), pole quality factor (Q) and bandwidth (BW).

In [40] a voltage-mode 3rd-order quadrature sine wave oscillator was presented which is based on an OTA. Three OTA and three grounded capacitors are used in the suggested arrangement. The outputs of two voltage-mode sinusoids in the proposed generating circuit with a phase difference of 90. Separate OTA slopes govern the oscillation state and frequency in an electrical manner.

In [41] a third-order quadrature oscillator was presented. The proposed circuit provided two quadrature voltage and current outputs utilising one current controlled transconductance differential amplifier (CCCDTA), one operational transconductance amplifier (OTA), and three grounded capacitors. The CCCDTA and OTA bias currents may be adjusted quadrature and electrically to regulate the oscillation condition and frequency.

2.4 Conclusion

In this chapter, after giving a brief introduction of harmonic oscillators, third order oscillators and quadrature oscillators, a brief summary of various third order sinusoidal oscillators realized with modern active building blocks was presented.

CHAPTER-3

IMPLEMENTATION OF THIRD ORDER QUADRATURE SINUSOIDAL OSCILLATOR USING OTRAS

3.1 Introduction

Oscillators are a key component of AC signal sources because they generate sinusoidal signals with predictable frequency and amplitude. The oscillator basically converts a one-way current from a DC power supply into an alternating waveform with the desired frequency. An oscillator is a circuit that generates sinusoidal waveforms with a set amplitude and frequency using a positive feedback amplifier. A quadrature oscillator is a circuit that generates two periodic signals that are in quadrature, i.e., they are 90 degrees out of phase. Quadrature oscillators are used in quadrature mixers and single-sideband generators in telecommunications, as well as vector generators and selective voltmeters. Quadrature oscillators are hence an important component in a wide range of communication and measurement systems.

There is no harmonic distortion in a pure sine wave voltage or current since it is a signal with only one frequency. Generally, the harmonic content of harmonic increases, harmonic distortion increases, the less a periodic signal resembles a sine wave.

In comparison to lower order oscillators, 3rd order oscillators provides improved frequency response, precision and efficiency. The quality of the sinusoidal wave improves as the order increases, and total harmonic distortion (THD) diminishes.

3.2 Review of Third Order Quadrature Sinusoidal Oscillator proposed in Literature earlier

In [34] a new third-order quadrature oscillator that uses an operational transresistance amplifier as its active element was presented. The proposed method provided high accuracy in determining the oscillation frequency and Two low-impedance quadrature voltage outputs for direct connection to loads.

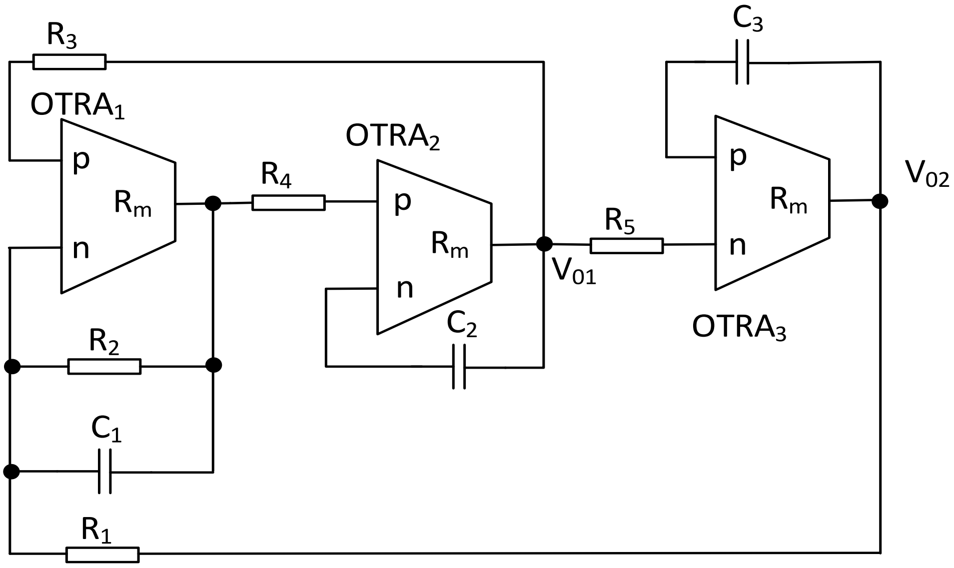

Fig.3.1 New third order quadrature oscillator using OTRAs proposed in [34]

In [35] a third order QO were presented based on OTRA (Operation Transresistance) topologies. The oscillator is made up of integrators that are both lossy and lossless. A matched transistor resistor working in the linear domain may be used to fully integrate the suggested architecture, which also allows for electronic frequency adjustment.

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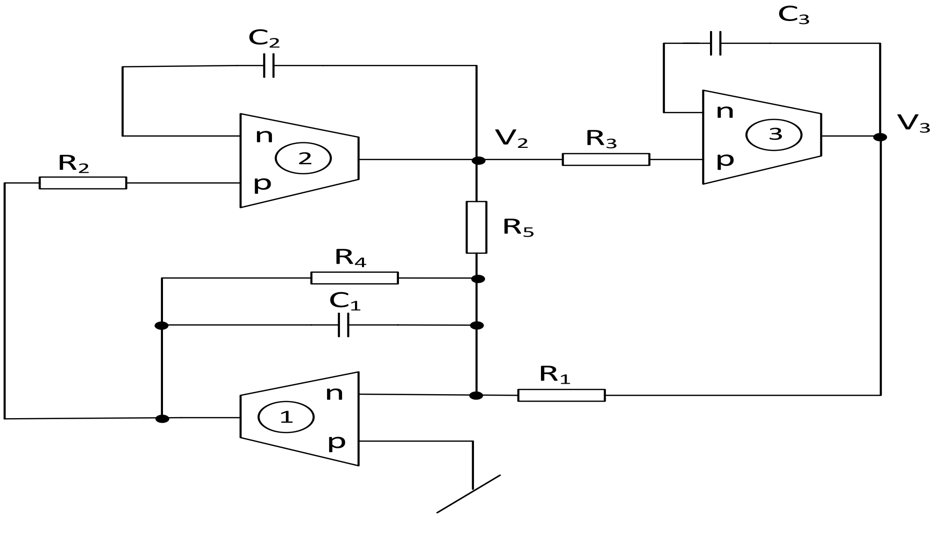

Fig.3.2 (a) Third order quadrature oscillator using three OTRAs proposed in [35]

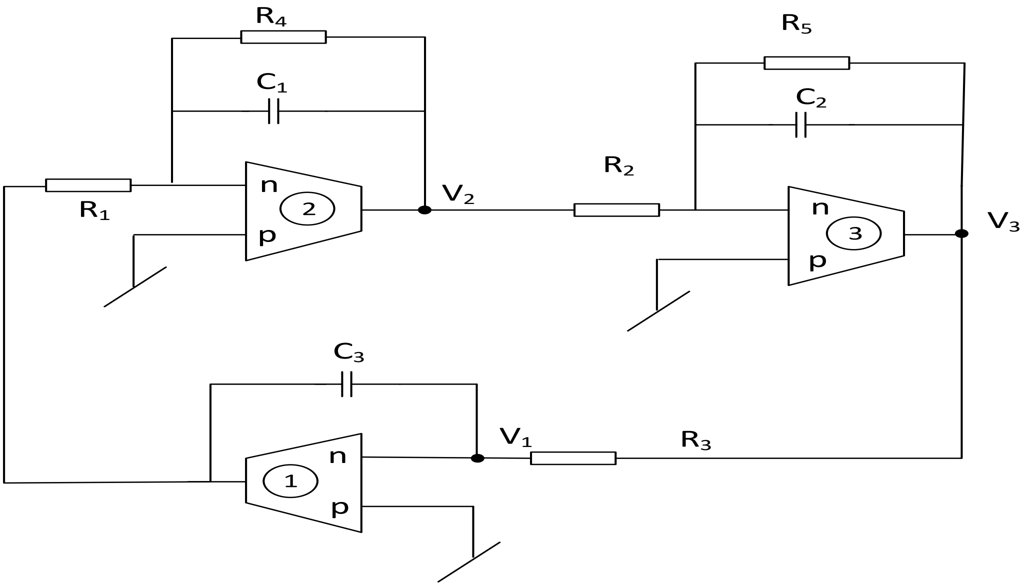

Fig.3.2.(b) Third order quadrature oscillator using OTRAs proposed in [35]

In [36] a third order sinusoidal oscillator was presented which was based on Operation Transresistance Amplifier. The proposed circuit consists of one OTRA combined with 3 resistors and 3 capacitors. This study included a review of previous designs and related formulations, non-ideal analyzes, and a discussion of the sensitivity of the proposed scheme.

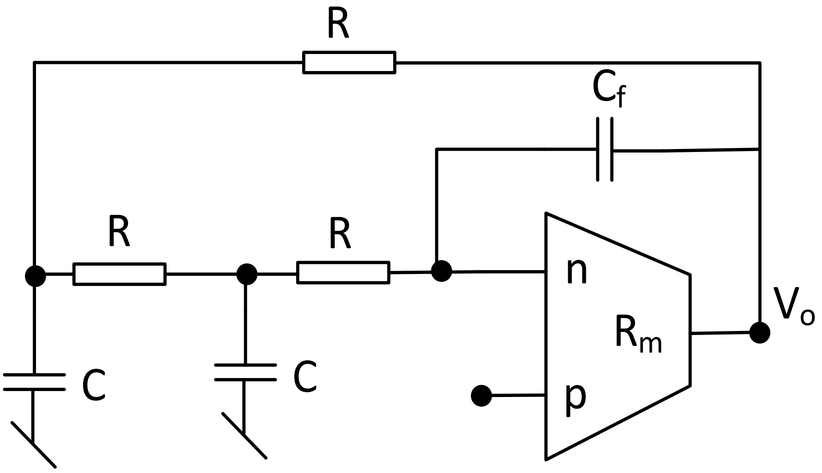

Fig.4.5. 3rd order quadrature oscillator using OTRA proposed in [36]

In [37] a voltage-mode 3rd order quadrature oscillator was proposed which was suitable for the MOSC implementation that electronically tunes the oscillation frequency. Analysis of circuit non-idealities is also provided, allowing self-compensation to be used for high-frequency applications.

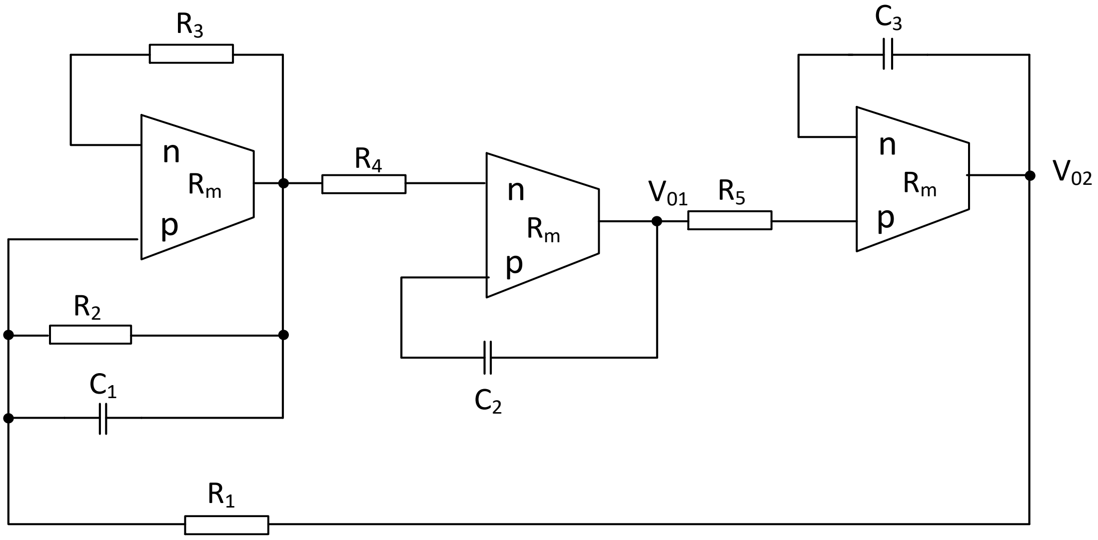

Fig.3.4 Voltage mode 3rd order quadrature oscillator using OTRAs proposed in [37]

In [38] a third-order sinusoidal oscillator-based OTRA was presented. The suggested design's non-ideal behaviour was investigated using one-pole and two-pole OTRA models. The active and passive sensitivities for the suggested structure were computed and determined to be less than one, making the circuit insensitive to component changes.

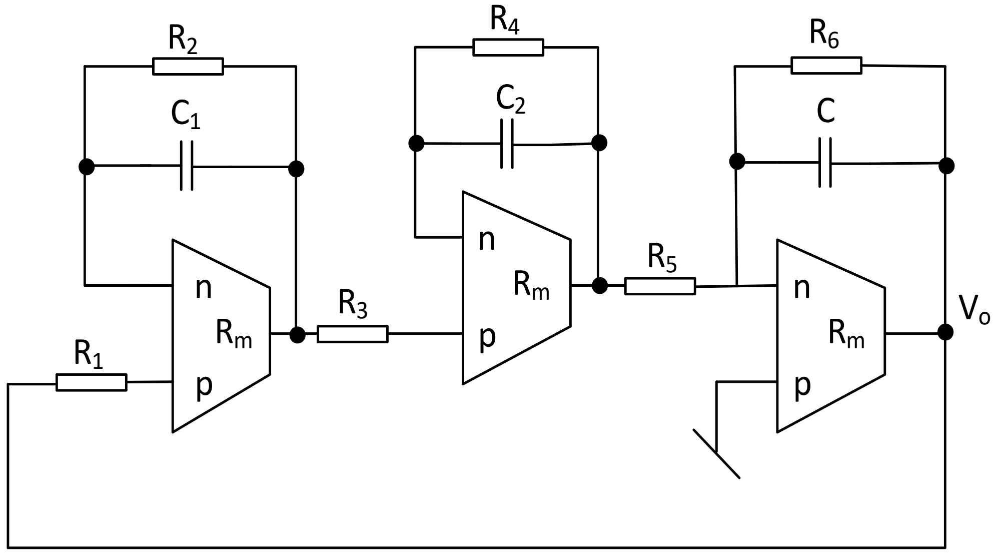

Fig.3.5 Third order quadrature oscillator using OTRAs proposed in [38]

3.3 Proposed Circuit

The proposed third order quadrature sinusoidal oscillator is shown in fig.3.6. It uses three OTRAs, three capacitors and six resistors forming a closed loop. The proposed circuit consists of two lossless integrator and one lossy integrator.

By applying KCL in OTRA 1, we get

$$V_{01}sC_1 = g_1V_{03} - g_6V_{02} \tag{3.1}$$

By applying KCL in OTRA 2, we get

$$V_{02}sC_2 = g_2V_{01} \tag{3.2}$$

By applying KCL in OTRA 3, we get

$$V_{03}sC_3 = g_5V_{02} - g_3V_{03} - g_4V_{02} \tag{3.3}$$

By solving equations (3.1), (3.2), (3.3) we get:

The characteristic equation is as follows:

$$s^3C_1C_2C_3 + g_3s^2C_1C_2 + g_2g_6sC_3 + g_2g_3g_6 + g_1g_2g_4 - g_1g_2g_5=0 \quad (3.4)$$

Condition of oscillation comes out to be:

$$R_5 = R_4 \quad (3.5)$$

Frequency of oscillation comes out to be:

$$f = \frac{1}{2\pi\sqrt{R_2R_6C_1C_2}} \quad (3.6)$$

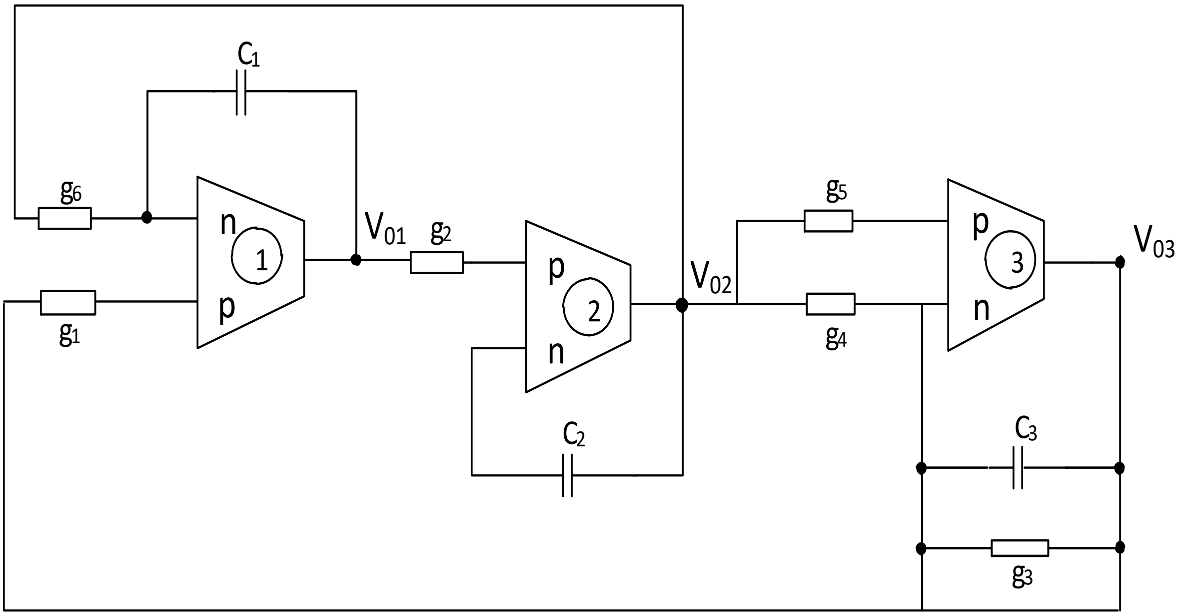

Fig.3.6 Proposed circuit

With the proper value of R_2 and R_6, FO may be set to the required value, and with proper values of R_4 or R_5, the desired CO can be obtained.

The current differencing property of the OTRA allows the resistors linked to the OTRA's input terminals to be implemented using MOS-transistors with complete non-linear elimination [43]. Two matched n MOSFETs are required for each resistor, as shown in Fig.3.7. This shows a MOS implementation of a resistor linked to OTRA's negative input.

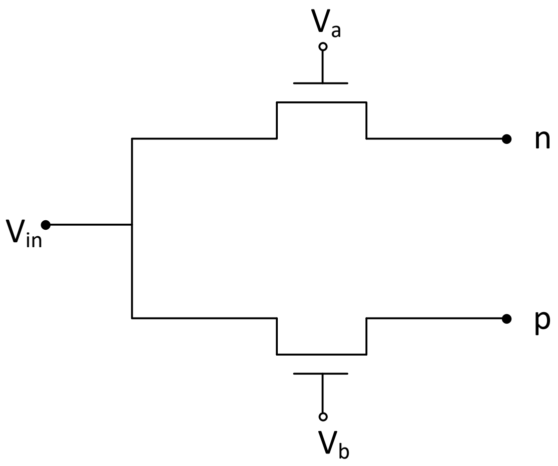

Fig.3.7 MOS based Resistor [43]

There are two input terminals of OTRA i.e. non-inverting and inverting which are represented by “p” & “n”. The drain voltage and the source voltage are same for both MOSFETs. The non-linearity is cancelled by the difference in currents passing through the 2 transistors. The realized resistance value can be expressed as:

$$R = \frac{1}{K_N(V_a - V_b)} \tag{3.7}$$

Where

$$K_N = \mu C_{OX} \frac{W}{L} \tag{3.8}$$

It is necessary to determine the KN of the transistor used to mount the resistor, COX, µ, and W / L represent standard transistor parameters.

3.4 NON IDEAL ANALYSIS:

By assuming that OTRA has an infinite R_m in the previous analysis, however R_m is finite practically. As a result, the impact of finite transresistance gain should be taken into account. R_m may be shown as:

$$R_m(s) = \frac{R_o}{1+\frac{s}{w_o}} \tag{3.9}$$

where R_o is transresistance gain of dc. For applications of high frequency the transresistance gain, (3.9) becomes,

$$R_m = \frac{1}{sC_p} \qquad (3.10)$$

Where $C_p = \frac{1}{R_o w_0}$ (3.11)

Taking this effect into account (3.1) (3.2) (3.3) and (3.4) modifies to

$$V_{01} = R_m(V_{03}g_1 - V_{02}g_6 - V_{01}sC_1) \qquad (3.12)$$

$$V_{02} = R_m(V_{01}g_2 - V_{02}sC_2) \qquad (3.13)$$

$$V_{03} = R_m(V_{02}g_5 - V_{02}g_4 - V_{03}g_3 - V_{03}sC_3) \qquad (3.14)$$

The characterstic equation comes out to be:

$$s^3\left(C_p^3 + C_2C_p^2 + C_1C_p^2 + C_1C_2C_p + C_3C_p^2 + C_2C_3C_p + C_1C_3C_p + C_1C_2C_3\right) + s^2\left(g_3C_3C_p + g_3C_p^2 + g_3C_1C_2 + g_3C_1C_p\right) + s\left(g_2g_6C_3 + g_2g_6C_p\right) + (g_2g_3g_6 + g_1g_2g_4 - g_1g_2g_5) = 0 \quad (3.15)$$

Condition of oscillation:

$$(g_3C_p^2 + g_3C_3C_p + g_3C_1C_p + g_3C_1C_2)\left(g_2g_6C_p + g_2g_6C_3\right) - \left(C_p^3 + C_2C_p^2 + C_1C_p^2 + C_1C_2C_p + C_3C_p^2 + C_2C_3C_p + C_1C_3C_p + C_1C_2C_3\right)(g_2g_3g_6 + g_1g_2g_4 - g_1g_2g_5) = 0 \qquad (3.16)$$

Frequency of oscillation:

$$f = \frac{1}{2\pi}\sqrt{\frac{g_2g_3g_6 + g_1g_2g_4 - g_1g_2g_5}{g_3C_p^2 + g_3C_3C_p + g_3C_1C_p + g_3C_1C_2}} \qquad (3.17)$$

The effects of Cp can be terminated by presetting the C_1, C_2, and C_3, thereby Self-Compensation can be realized.

3.5 Result and Simulation

In Fig.3.8 the CMOS representation of OTRA[44] is shown. Assuming that all transistor groups (M1-M26) is matched and all operate in the saturation zone. The current mirrors are represented by transistor pairs (M_{17}-M_{18}) and the transistor pairs (M_5- M_8 & M_{13}-M_{16})are the pmos mirrors and (M_9- M_{12} & M_{19}-M_{22}) are the nmos mirrors.

The high open loop gain differential OTRA is realized in CMOS which is based on the A.K.Singh and P.Kumar proposed in [44] . The aspect ratio details are given in Table3. The values of DC bias currents (I_b) are 40µA and the value of voltages (V_{dd} and V_{ss}) are ±2.5V.The CMOS model is the same for all circuits. The transistor model is a 250nm CMOS process provided by TSMC.

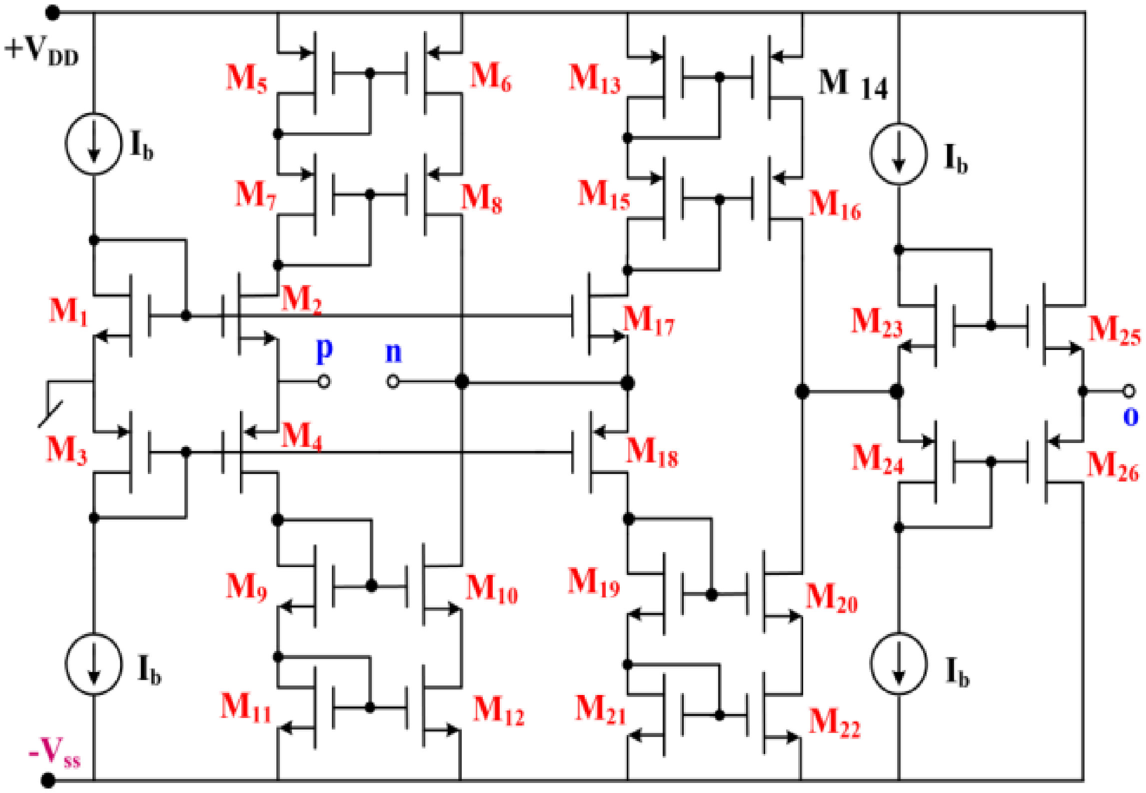

Fig. 3.8 OTRA's CMOS Implementation [44]

The Operational transresistance amplifier is characterized through PSPICE simulation to verify its functionalities. The aspect ratio of various transistors are taken same as in [44] and are reproduced in Table 3.1.

Table3.1 Aspect Ratio of MOSFETs[44]

S.No.	MOSFETs	W(µm)	L(µm)
1.	M_1,M_2,M_{17},M_{23},M_{25}	25	0.25
2.	M_3,M_4,M_{24},M_{26},M_{18}	50	0.25
3.	M_5,M_6,M_7, M_8, M_9, M_{10}, M_{11}, M_{12}, M_{19}, M_{20}, M_{21}, M_{22}, M_{13}, M_{14}, M_{15}, M_{16}	2.5	0.25

The DC characteristic of the OTRA [44] by taking the different values of I_n from -60µA to 60µA with step size of 20µA and I_p is taken 80µA is shown below. The values of L of all mosfets are taken as 250nm and W as per the table 3.1.

The simulations are performed using PSPICE, carried out using TSMC 250nm CMOS process parameters as mentioned earlier. The circuit was designed with the parameters: C1 = C2 = C3 = 0.1 n, $R_1 = R_2 = R_3 = R_6 = 5$ k, $R_4 = 7$ k and $R_5 = 8$k . The value of R_2 was changed to get the different frequency of oscillation in equation (3.6) shown in Table 4.2. The value of power supplies are +-2.5 V and biasing current= 40µA. The output characteristics of OTRA is shown in Fig. 3.9.

By using equation (3.6) we get,

$$f = \frac{1}{2\pi\sqrt{R_2 R_6 C_1 C_2}} \tag{3.18}$$

Now,

R_2=5kΩ

R_6=5kΩ

C_1=0.1nF

C_2=0.1nF

Putting these values to equation (3.18) to get the theatrical value of frequency of oscillation we get,

$$f = \frac{1}{2\pi\sqrt{(5k)(5k)(0.1n)(0.1n)}}$$

$$f = 318.47\text{kHz}$$

Now, simulated value of frequency of oscillation came out to be 300 kHz and after calculation, theoretical value was calculated as 318.47 kHz by putting all the values of R_2, R_6, C_1, C_2 which are mentioned above.

Table 3.2 Variation of output voltages with respect to frequency

S.No.	Frequency (kHz)	V_{01} (V)	V_{02} (V)
1.	470	2.202	1.264
2.	400	2.186	1.608
3.	355	2.167	1.889
4.	325	2.129	2.09
5.	300	2.041	2.18
6.	280	1.91	2.23
7.	265	1.79	2.243
8.	250	1.69	2.255
9.	235	1.59	2.262
10.	225	1.52	2.265
11.	165	1.06	2.245
12.	135	0.85	2.209
13.	120	0.725	2.168
14.	105	0.634	2.123

As it is visible the frequency of oscillation depends on two resistances and two capacitors. We can take any of the resistance to get the different frequency out of R_2 and R_6 .Now, R_2 is varied from 1 to 50kΩ so that variation of frequency of oscillation is shown in Table 4.2 represents the variation of FO with respect to R_2. Table 4.1 represents the variation of output voltage by varying the frequency. These values are achieved by changing the values of R_2 as mentioned earlier.

Table 3.3 Variation of FO with respect to R_2

S.No.	R_2 (kΩ)	Frequency (kHz)
1.	1	470
2.	2	400
3.	3	355
4.	4	325
5.	5	300
6.	6	280
7.	7	265
8.	8	250
9.	9	235
10.	10	225
11.	20	165
12.	30	135
13.	40	120
14.	50	105

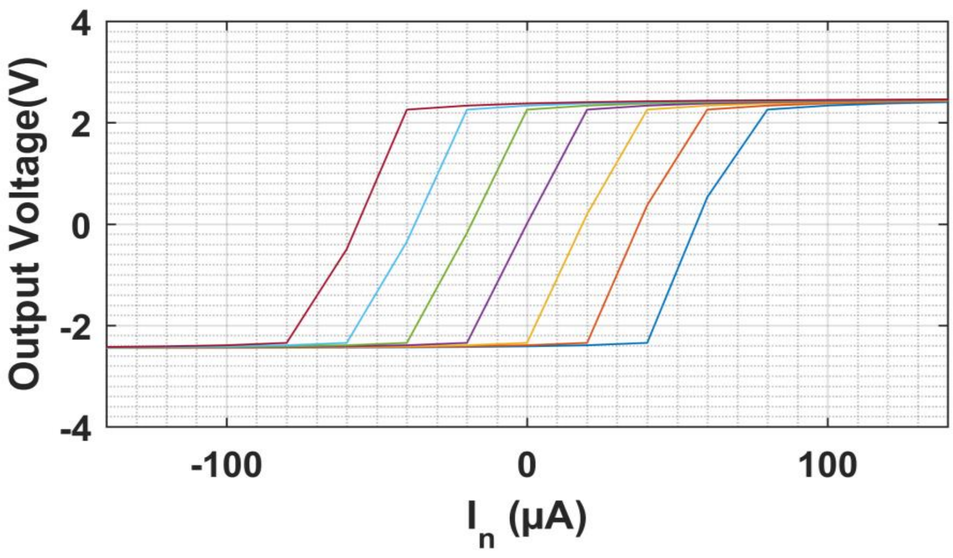

Fig.3.9 Output Voltage of OTRA

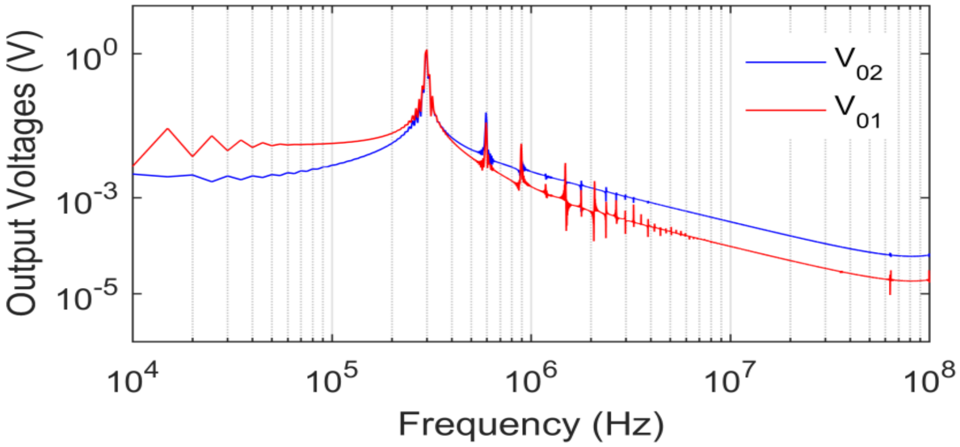

Fig.3.10 Frequency spectrum of output of proposed circuit

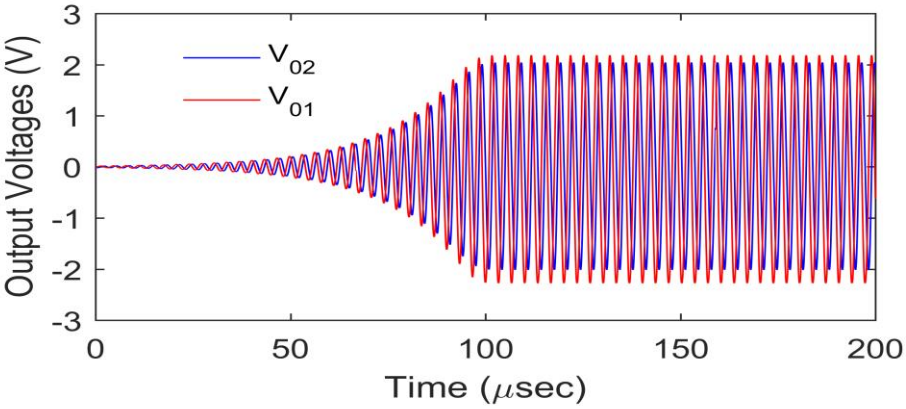

Fig.3.11 Simulated quadrature output waveform.

The fig.3.10 shows the frequency spectrum of the proposed circuit & the simulated quadrature output waveform which can also be called transient output of the presented circuit which is shown above in the fig.3.11.

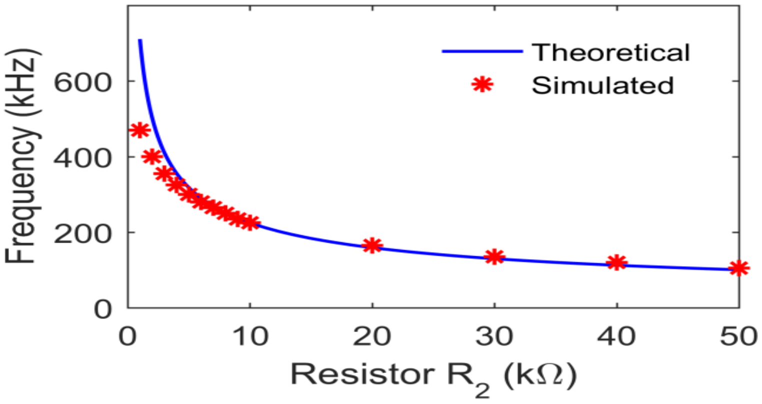

Fig. 3.12 Varied the frequency of oscillation with R_2.

By using equation (3.6) the frequency of oscillation i.e.FO depends on two resistors value which are R_2 and R_6, by changing the value of R_2 and using the equation (3.6), the theoretical response is observed and plotted in fig.3.12.Using the table 3.2 the simulated plot is observed and plotted in fig.3.12.

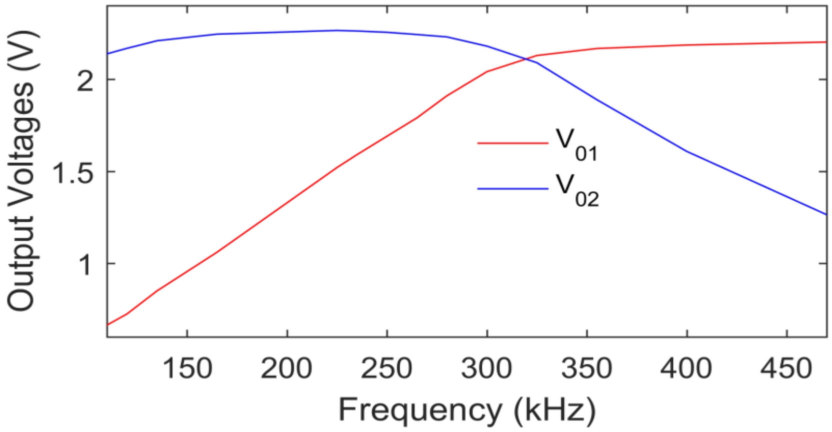

Fig.3.13 Variation of output voltages with frequency

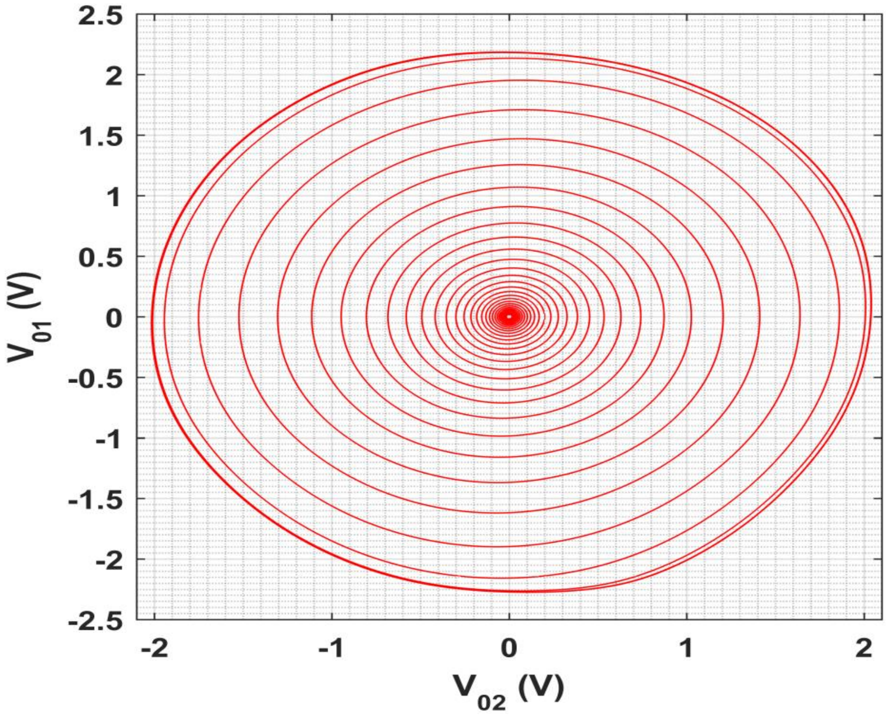

Fig.3.14 Quadrature Relationship between Generated Waveforms

Using the table 3.1, the variation of output voltage is observed and noted by varying the frequency shown in fig.3.13. These values are achieved by changing the values of R_2 as mentioned earlier. Quadrature relationship between generated waveforms is also observed and plotted as shown in fig.3.14.

CHAPTER-4

CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

In chapter 1, Operational Amplifier and it's common topologies has been discussed in detail. Operational transresistance amplifier(OTRA) is explained with its symbol, matrix, equation and schematic diagram. Some of the important applications of OTRA is also shown in this chapter.

In chapter 2, Literature survey is presented which includes explanation of various related topics like third order oscillators, quadrature oscillators and many more. Barkhausen criterion is also explained with wien bridge oscillator and RC phase shift oscillator. After that Oscillators are discussed in detail with quadrature oscillator and higher order oscillators.

In chapter 3, CMOS implementation of OTRA is explained with details of each mosfet. Total 26 mosfets, 4 biasing currents and supply voltages are used in the structure of OTRA. The W/L ratio of all mosfet is also shown in tabular form. The dc characterstics of OTRA is also plotted in this section. The circuit of 3rd order quadrature sinusoidal oscillator is proposed. In this section characteristic equation, FO and CO are calculated. This section includes non-ideal analysis as well. Then, the result and simulation of 3rd order circuit is shown. The frequency analysis and the simulated quadrature output waveform which can also be called transient output of the proposed circuit is shown in this chapter.

4.2 Scope for future work

This dissertation describes some of the sinusoidal oscillators using OTRA. There are always opportunities for improvement. The work presented can be further improved by making the circuit with less number of resistors and capacitors. The circuit can be made electronic tunable by replacing resistors with MOS based Resistor. The work presented can be further improved by decreasing the number of OTRAs.

Through literature reviews, it is observed that OTRA based nonlinear applications have received less attention, which is an area where further investigation can be done.

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