A DISSERTATION ON

INVESTIGATION ON PERFORMANCE PARAMETERS OF LINEAR OSCILLATORS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

(VLSI AND EMBEDDED SYSTEM DESIGN)

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2012-2014

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This is certified that the dissertation entitled "**Investigation on Performance Parameters of Linear Oscillators"** is a work of **Rohit Singh** (University Roll No.-2k12/vls/17) a student of Delhi Technological University. This work is completed under my direct supervision and guidance and forms a part of Master of Technology (VLSI and Embedded System Design) course and curriculum. He has completed his work with utmost sincerity and diligence.

The work embodied in this major project has not been submitted for the award of any other Institute / University to the best of my knowledge.

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ACKNOWLEDGEMENT

It is distinct pleasure to express my deep sense of gratitude and indebtedness to my Project Guide **Dr. Neeta Pandey,** Associate Professor, Department of Electronics and communication, Delhi Technological University, for her invaluable guidance, encouragement and patient reviews. Her continuous inspiration only has made me complete this dissertation. Without her help and guidance, this dissertation would have been impossible. She remained a pillar of help throughout the project.

I am extremely thankful to **Prof. Rajiv Kapoor**, Head of the Department, Electronics and communication, Delhi Technological University and Dr. Rajeshwari Pandey, associate Professor, DTU for the motivation and inspiration. I would also like to take this opportunity to present my sincere regards to all my teachers those who came to my help in some way for marking the project successful. I am also thankful to all non-teaching staff of Electronics and communication Department for providing me unconditional and any time access to the resources.

I am grateful to my parents for their moral support all the time, they have been always around to cheer me up, in the odd times of this work. I am also thankful to my classmates for their unconditional support and motivation during this work.

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ABSTRACT

The objective of this report is to design second and third order linear sinusoidal oscillators and study their performance parameters. The approach used here for design of linear oscillators employs a positive-feedback loop consisting of an amplifier and an RC or LC frequency-selective network. There are various circuit topologies available for making oscillators, most common of them is, two integrator loop oscillators realized using different active building blocks. This Project Report contains several other topologies like three low pass filters with an inverting gain stage in a loop, sallen key low pass filter with lossy integrator and Non-inverting Amplifier in a loop, etc. There are three second order and three third order oscillator circuits proposed in this work. Along with designing of second and third order oscillators, this project report contains study of certain performance parameters of oscillators like Phase noise analyses, Total Harmonic Distortion (THD) and its variation with frequency, Frequency Stability (Short-term and Long term), Frequency Offset, Effects of Power supply variations. Then, three among the studied parameters are used to evaluate performance of the proposed oscillators.

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INTRODUCTION

1.1 INTODUCTION

In mathematical sense, the sine wave is one among the essential waveforms as any wave shape can be created as Fourier combination of basic sine wave. It has also been widely used as a test waveform or a carrier signal. The generation of sinusoids [1] is based on primarily two approaches. The first one relies on placing an amplifier and an RC or LC frequency-selective network in a positive-feedback loop. Here, the amplitude of sine waves is limited by a nonlinear mechanism which is attained either by amplifying device nonlinearity or with a separate circuit. These circuits generate waveforms using resonance phenomenon and are also known as Linear Oscillators. The second method which generates sinusoids by appropriately shaping a triangular waveform lies in different category. The performance of linear oscillator is determined from parameters such as phase noise, Total Harmonic Distortion, frequency stability and effects of power supply variations.

The block diagram of linear oscillator based on the first approach is given in Fig. 1.1 where $A(j\omega)$ and $\beta(j\omega)$ respectively represent amplifier gain and the transfer function of the feedback path. The Barkhausen stability criterion gives a mathematical condition for oscillations in a linear circuit. It states that loop gain ($\beta(j\omega)\, A\,(j\omega)$) should satisfy the following conditions for sustained steady-state oscillations only at frequencies for which:

1. The loop gain is equal to unity in absolute magnitude, i.e., $|\beta A| = 1$ and
2. The phase shift around the loop is zero or an integer multiple of 2π i.e., $phase(\beta A) = 2\pi n, n\epsilon\ 0,1,2 \ldots..$

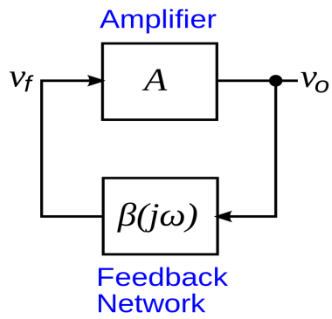


Fig 1.1 General oscillator diagram

The linear oscillators can be classified depending on the elements (active and / or passive) employed in the feedback loop or on the basis of accuracy of the response they provide. The oscillators falling in first class can be further divided into two parts on the basis of passive elements. The first approach uses R and C sections in such a way that loop gain satisfies the Barkhausen criterion of phase and magnitude. These are also called RC phase shift oscillator. In second approach, a tuned circuit (often called a tank circuit) consists of an inductor (L) and capacitor (C) connected together. Here, charge flows back and forth between the capacitor's plates through the inductor, so the tuned circuit can store electrical energy oscillating at its resonant frequency. There are small losses in the tank circuit, but the amplifier compensates for those losses and supplies the power for the output signal. The LC tank oscillators namely Hartley and Colpitts oscillators belong to this class. The RC phase shift oscillators are mostly used to generate lower frequencies, for example in the audio range while LC oscillators are often used at radio frequencies. The accuracy of the response is decided by the order of characteristics equation obtained from loop gain of oscillators. The characteristics equation can be of order n such that 2,3,4.. . Hence, oscillators can be of second, third and higher orders. It is generally inferred that higher order oscillators provide better response.

Yet another representative class of oscillator depends on type of response e.g. single phase, quadrature phase and multiphase. The single phase oscillator provides one response whereas quadrature oscillator gives two sinusoids with 90◦ phase difference. The quadrature oscillator finds applications in telecommunications for quadrature mixers and single-sideband generators, for measurement purposes in vector generators or selective voltmeters. The multiphase oscillator yields multiple responses which are equally spaced in phase.

This work encompasses the development of some second and third order oscillators based on active blocks such as Op-amp and Operational Transresistance amplifier and subsequently evaluating their performance. In the following section, a brief overview of these blocks is given.

1.2 Operational amplifier

The operational amplifier (OPAMP) is one of the most useful and important components of analog electronics. An op-amp is a DC-coupled high-gain electronic voltage amplifier with a differential input and, commonly, a single-ended output. Ideally the op-amp amplifies only the difference in voltage applied between its two inputs (V_+ and V_-), which is called the differential input voltage. The output voltage of the op-amp is given by the equation,

$$V_0 = (V_+ - V_-)A_0 \tag{1.1}$$

Where V_+ is the voltage at the non-inverting terminal and V_- is the voltage at the inverting terminal and A_0 is the open-loop gain of the amplifier.

The ideal operation is difficult to achieve and the non-ideal conditions often raise limitations like finite impedances, their primary limitation being not especially fast. The typical performance degrades rapidly for frequencies greater than 1MHz, although some models are designed especially for higher frequencies. High input impedance at the input terminals (ideally infinite) and low output impedance at the output terminal(s) (ideally zero) are important typical characteristics. The other important fact about op-amps has large open-loop gain which may measured from a configuration when there is no feedback loop from output back to input. A typical open-loop voltage gain is ~ 10^4 -10^5 .

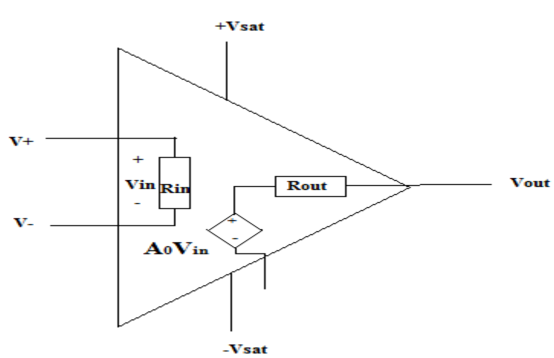


Figure 1.2 Non ideal internal circuit of Op-amp

An ideal op-amp is usually considered to have the following properties, and they are considered to hold for all input voltages:

- Infinite open-loop gain.
- Infinite voltage range available at the output (V_{out}) (in practice the voltages available from the output are limited by the supply voltages $+V_{SAT}$ and $-V_{SAT}$)
- Infinite bandwidth
- Infinite input impedance
- Zero input current
- Zero input offset voltage
- Infinite slew rate
- Zero output impedance
- Infinite Common-mode rejection ratio (CMRR)
- Infinite Power supply rejection ratio for both power supply rails.

1.4 Operational Trans-resistance Amplifier

Operational Transresistance Amplifier (OTRA) is a high gain current input, voltage output amplifier [5]. The OTRA being a current mode building block inherits the advantages of current mode processing as well as it is free from parasitic input capacitances and resistances as its input terminals are virtually grounded and hence, non-ideality problem is less in circuits implemented using OTRA.

The symbol of OTRA is illustrated in Fig.1.3. The OTRA is a three terminal device described by matrix equation:

$$\begin{bmatrix} V_p \\ V_n \\ V_O \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_O \end{bmatrix} \tag{1.2}$$

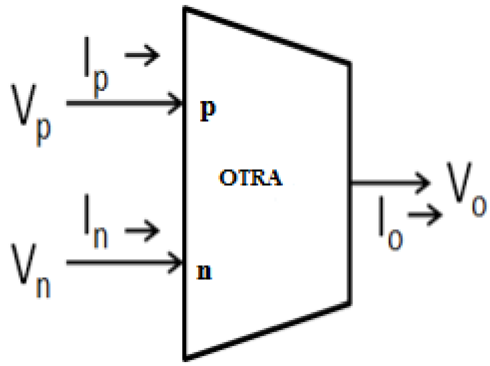


Fig.1.3 Symbol of OTRA

Its output terminal equation is described as follows:

$$V_{OUT} = R_m \ (I_p - I_n) \tag{1.3}$$

Where R_m =trans-resistance of OTRA

It is clear from (1.3) that both input and output terminals are characterized by low impedance, thereby eliminating response limitations incurred by capacitive time constants. The input terminals are virtually grounded leading to circuits that are insensitive to stray capacitances [6]. Ideally, the transresistance gain, R_m, approaches infinity, and external negative feedback must be used which forces the input currents, Ip and In, to be equal [7]. Thus OTRA must be used in a negative feedback configuration.

As an ideal OTRA is usually considered to have the following properties and they are considered to hold for all input voltages:

- Low input impedance.
- Low output impedance
- Infinite trans resistance gain i.e. $R_m = \infty$

1.4 Organization of thesis

The thesis is organized into following chapters:

Chapter 2: This chapter describes the performance parameters of the oscillators mainly the phase noise, Total Harmonic Distortion, Frequency Stability and Effects of power supply variations. It also contains mathematical formulae for oscillators employing second- and third-order equivalent low pass filters in their feedback loop. The mathematical models are used to compute phase noise sidebands. Several graphs representing the phase noise characteristics of various types of oscillators are included. Along with this it also contains discussion about Total Harmonic Distortion and its variation with frequency.

Chapter 3: In this chapter a detailed description of Second order circuits are given. Oscillators are designed using OTRA. Several new topologies for constructing oscillators are discussed like OTRA based Hartley and Colpitts etc.

Chapter 4: In this chapter a detailed description of Third order circuits are given. Several new topologies for constructing oscillators are discussed like sallen key low pass filter, lossy integrator and Non-Inverting Amplifier in a loop etc. Oscillators are formed using two active blocks namely OP-AMP and OTRA.

Chapter 5: This chapter analyzes the simulation results of the circuits proposed in this dissertation. The transient as well as frequency response of the proposed circuits are also included.

Chapter 6: This chapter analyses the proposed oscillators on the basis of oscillators parameters described in the chapter 2 and then compare the different circuits. Graphs and plots related to circuits are also given in this chapter.

Chapter 7: In this section conclusion of the thesis work and future scope of the work are presented.

References

[1] Sedra AS, Smith KC. Microelectronic circuits. 4th ed. Oxford University Press; 1998, p. 73–86.

[2] Van Valkenburg M. Analog filter design. Holt, Rinehart and Winston; 1982, p. 549–69.

[3] Budak A. "Passive and active network analysis and synthesis". Houghton Mifflin Company; 1974, p. 458–85.

[4] Khaled n. Salama, Ahmed m. Soliman, 1999 CMOS operational transresistance amplifier for analog signal processing

[5] Chen, J. J., Tsao H. W., Chen, C. C. Operational transresistance amplifier Using CMOS Technology. Electronics Letters. 1992, vol. 28, no. 22, p. 2087–2088.

[5] Chen J. J., Tsao H. W., Liu S. and Chui W., Parasitic-capacitance-insensitive current-mode filters using operational transresistance amplifiers, IEE Proc. Circuits Devices and Systems 1995, vol. 142, no. 3, p. 186–192.

[6] Salama K. N., Soliman A. M., CMOS operational transresistance amplifier for analog signal processing. Microelectron J. 1999, vol. 30, issue 3, p. 235–45.

[8] Ahmed M. Soliman, Two integrator loop quadrature oscillator:A review; Journal of Advanced Research (2013) 4, 1–11

[9] Soliman AM. Transformation of oscillators using Op Amps, unity gain cells and CFOA. Analog Integr Circ S 2010;65:105–14.

[10] Chen JJ, Taso HW, Liu SI, Chiu W. Parasitic-capacitance insensitive current-mode filters using operational transresistance amplifiers. Proce IEE – G 1995;142:186–92.

[11] Evans S. Current feedback Op Amp applications circuit guide. Colorado: Complinear Corporation; 1988, p. 11.20–.26

[12] Salama KN, Soliman AM. Novel MOS-C quadrature oscillator using differential current voltage conveyor. In: Circuits andsystems, 42nd midwest symposium on circuits and systems, New Mexico, USA, vol. 1; 1999. p. 279–82.

[13] Acar C, O¨ zoguz S. A new versatile building block: current differencing buffered amplifier suitable for analog signalprocessing filters. Microelectron J 1999;30:157–60.

[14] M. T. Abuelma'atti and H. A. Al-Zaher, "Current-mode sinusoidal oscillators using single FTFN," IEEE Trans. Circuits and Systems-II: Analog and Digital Signal Proc., vol. 46, pp. 69-74, 1999.

[15] U. Cam, A. Toker, O. Cicekoglu, and H. Kuntman, “Current-mode high output impedance sinusoidal oscillator Configuration employing single FTFN,” Analog Integrated Circuits and Signal Proc., vol. 24, pp. 231- 238, 2000.

Chapter-2

PERFORMANCE PARAMETERS OF SINUSOIDAL OSCILLATORS

Sinusoidal Oscillators can be analyzed using different performance parameters present in literature. This chapter describes the performance parameters of the oscillators namely the phase noise, total harmonic distortion, frequency stability and effects of power supply variations. It contains mathematical formulae for oscillators employing second and third-order equivalent low pass filters in their feedback loop. The mathematical models are then used to compute phase noise sidebands. Along with this it also contains discussion about Total Harmonic Distortion and its variation with frequency.

2.1 Phase Noise

2.1.1 Literature Survey

The harmful effects of phase noise from the transmitter's exciter stage and the receiver's local oscillators are very old and known to exist since World War II. Since then much research has been directed toward improving the phase noise of oscillators. This research is documented in numerous articles. In 1960, W. A. Edson [1] first provided a mathematical formula for the FM-noise deviation of linear and nonlinear oscillators. D. B. Leeson also published a paper in 1966 [2], in which a heuristic solution for computing the phase noise sideband in the vicinity of the carrier frequency was presented. A few years later, G. Sauvage [3] published an exact derivation of Leeson's formula using the theories and mathematical rules of random (stochastic) processes. This project report uses the result of Sauvage's derivation, substituting higher order low-pass filter transfer functions for simple resistance- capacitance (RC) low-pass filter transfer functions. Following section describes the leeson's model in detail.

2.1.2 Leeson's oscillator model

The simple feedback oscillator model is shown in Figure 2.1. It consists of an amplifier with internal noise $\emptyset o$ in the forward loop and a low pass filter, which can be of order n where $n\epsilon$ 1,2 ….. in the feedback loop. $\emptyset s$ and $\emptyset e$ are phase noise at two different points shown in the Fig 2.1. According to Sauvage [3], the following equation can be derived from figure:

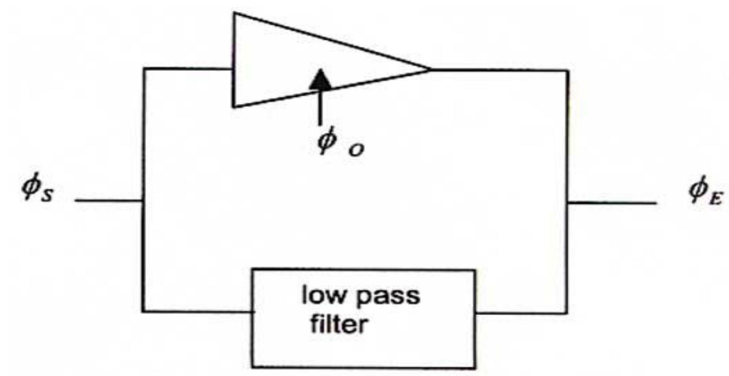


Fig 2.1Simple feedback oscillator model

$$\emptyset s(t) + \emptyset o(t) = \emptyset e(t) \tag{2.1}$$

$$\emptyset s(t) = \int_{-\infty}^{\infty} \emptyset e(t) hbf\,(t' - t) dt' = \emptyset e(t) * hbf(t) \tag{2.2}$$

Where hbf(t) is the impulse response of the equivalent low-pass filter (the '*' in the equation denotes the convolution product), $\varphi_S(t)$ converges for nearly all samples of $\varphi_E(t)$. The filter is linear and time invariant. Applying these conditions and using the autocorrelation function of $\varphi_o(t)$ and the cross correlation functions of $\emptyset s(t)$ and $\emptyset e(t)$, as well as the Wiener-Khintchin theorem[3], following equation can be derived:

$$S\emptyset e(\omega) = S\emptyset o(\omega).\left[(H(j\omega) - 1)(H^*(j\omega) - 1)\right]^{-1} \tag{2.3}$$

The "*" denotes the conjugation process. This is Leeson's general formula for any type of equivalent low-pass filter. The $S\emptyset e(\omega)$ is the phase noise spectrum at the output port of the oscillator as a result of the $S\emptyset o(\omega)$ phase noise excitation. Now considering these results for a simple low-pass RC filter,

$$H(j\omega) = \left(\frac{\alpha}{i\omega+\alpha}\right), \qquad H^*(j\omega) = \left(\frac{\alpha}{\alpha-i\omega}\right) \tag{2.4}$$

Where

$$\alpha = \left(\frac{\omega_o}{2Q_L}\right)$$

ω_o is the angular carrier (operating) frequency of the oscillator, and Q_L is the loaded quality factor of the resonator.

Equation (2.4) is substituted into (2.3). After mathematical reduction, following formula can be obtained:

$$S\emptyset e(\omega) = S\emptyset o(\omega).\left[1 + \left(\frac{\alpha}{\omega}\right)^2\right] \tag{2.5}$$

Now, in a similar way next section of this chapter derived the formula for third order filters present in higher order oscillators.

2.1.3 Third-order equivalent low-pass filter in the feedback loop

The transfer function of the third-order equivalent low-pass filter can be written as the multiplication of a first- and a second-order low-pass filter transfer function:

$$H(j\omega) = \left(\frac{1}{1-\left(\frac{\omega}{\omega_i}\right)^2 - \frac{j2\zeta\omega}{\omega_i}}\right)\left(\frac{1}{i\frac{\omega}{\omega_3}+1}\right) \tag{2.6}$$

After executing the multiplication and introducing $\omega_3 = \mu\omega_i$ results shown in (2.7),

$$H(j\omega) = \left(\frac{1}{1-\left(\frac{\omega}{\omega_i}\right)^2\left[1+\frac{2\zeta}{\mu}\right]+j\frac{\omega}{\omega_i}\left[2\zeta+\frac{1}{\mu\left\{1-\left(\frac{\omega}{\omega_i}\right)^2\right\}}\right]}\right) \tag{2.7}$$

Where μ is a dimensionless multiplier. Inserting Equation (2.7) into (2.3), after simplification, following equation is obtained:

$$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{\left(1+\frac{1}{\left(\frac{\omega}{\omega_i}\right)^2}\right)\left(1-2\left(\frac{\omega}{\omega_i}\right)^2\left[1+\frac{2\zeta}{\mu}\right]\right)}{\left(\frac{\omega}{\omega_i}\right)^2\left[1+\frac{2\zeta}{\mu}\right]^2+\left[2\zeta+\frac{1}{\mu}\left\{1-\left(\frac{\omega}{\omega_i}\right)^2\right\}\right]^2} \quad (2.8)$$

Equation (2.8) has been plotted against $x = \left(\frac{\omega}{\omega_i}\right)$ normalized frequency with different ζ parameters and shown in Figure 2.2.

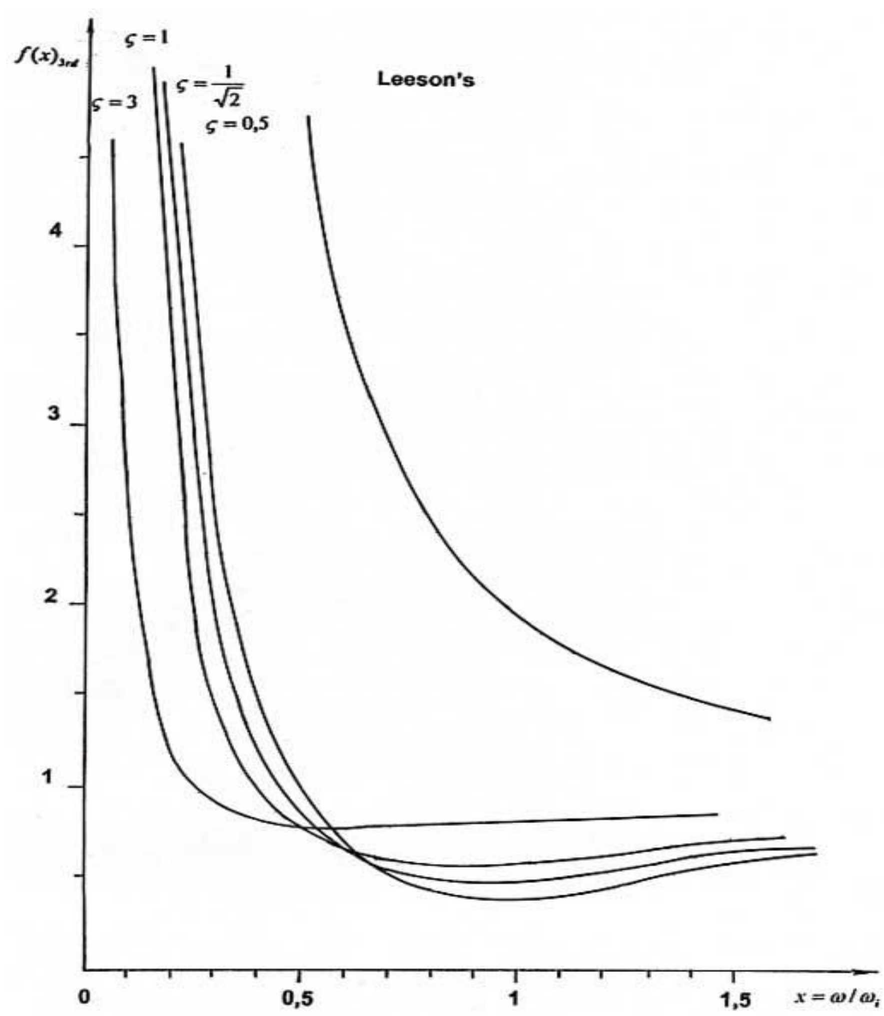


Fig 2.2 Phase Noise Response of Third-order low-pass loop filter.

According to the plotted graphs, the oscillators produce more phase noise in the near vicinity of the oscillation frequency, but as soon as we move away from oscillation frequency phase noise declines sharply with various slopes and the slope is dependent on different values of ζ. As the value of ζ is decreased the steepness of slope declines. Using this model, higher order equivalent low-pass loop filters can be analyzed, and it is generally inferred that every increment in the degree of the loop filter produces an additional 6 dB per octave steepness enhancement. Above mathematical formulas are used in phase noise analyses of third order oscillators in later chapters and phase noise curve like shown in Fig 2.2 is obtained for single value of ζ.

2.2 TOTAL HARMONIC DISTORTION

The Total harmonic distortion (THD) can be defined in terms of harmonics and distortion. Harmonics is related frequencies that are integer multiples of the waveform's fundamental frequency. For example, given a 60Hz fundamental waveform, the 2nd, 3rd, 4th and 5^{th} harmonic components will be at 120Hz, 180Hz, 240Hz and 300Hz respectively. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. The ideal sine wave has zero harmonic components.

Mathematically, the THD is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave and is expressed as:

$$THD = \left(\frac{\sqrt[2]{V_2^2 + V_3^2 + V_4^2 + V_5^2 \ldots + V_n^2}}{V_1} \right) * 100 \qquad (2.9)$$

Above equation shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present in signal. PSPICE tool can gives THD at a particular centre frequency with as many numbers of harmonics as desired and also the value of voltages at different harmonics. However, in this project report, THD is studied with respect to changing frequency of oscillations i.e. THD is calculated at one frequency of oscillation and then frequency is changed and THD is calculated at this changed frequency also, thus forming a plot of THD versus Frequency curve. This plot clearly describes the variations of THD with frequency. Hence, study oh this plot can allow us to find out the frequency at which THD is minimum. Such analysis is done in chapter 5.

2.3 Frequency Stability

The frequency stability is classified as long term and short term and is briefly described in the following subsection.

2.3.1 Long term instabilities [7]

These are slow changes in oscillator frequency over time (e.g., minutes, hours, or days), generally due to temperature changes and/or oscillator aging. For good oscillators, this instability is measured in parts per million (ppm). Parts per million is a similar to describing the instability in terms of percentage change in oscillator frequency. However, instead of expressing this change relative to one hundredth of the oscillator frequency ω_o (i.e., one percent of the oscillator frequency), it is express in a change relative to one-millionth of the oscillator frequency $\omega_{o.}$ Another way of expressing "parts per million" is "Hz per MHz" i.e., the amount of frequency change $\Delta\omega_r$ in Hz, divided by the oscillator frequency expressed in MHz. For example, say an oscillator operates at a frequency of f_o = 100MHz. This oscillator frequency will can (slowly) change as much as Δf_r = ±10 kHz over time. We thus say that the long-term stability of the oscillator is:

$$\frac{\Delta f_r}{f_o} = \frac{\pm 10000}{100} = \pm 100ppm$$

2.3.2 Short-term instabilities [7]

The short-term instabilities of oscillators are commonly referred to as phase noise which is a result of having imperfect resonators. Phase noise is observed in radio receivers as Noise sidebands. In oscillators it makes the frequency response less sharp at frequency of oscillation and its harmonics (shown in Fig 2.3) which leads to time jitter in time domain. Jitter[9] is fast variation in frequency (faster than 10Hz) which is different from frequency variations due to aging as they are slow variations (and known as "Wander"[9]).Phase noise in oscillators is high at frequencies close to oscillation frequency and declines very sharply as we move away from frequency of oscillation.

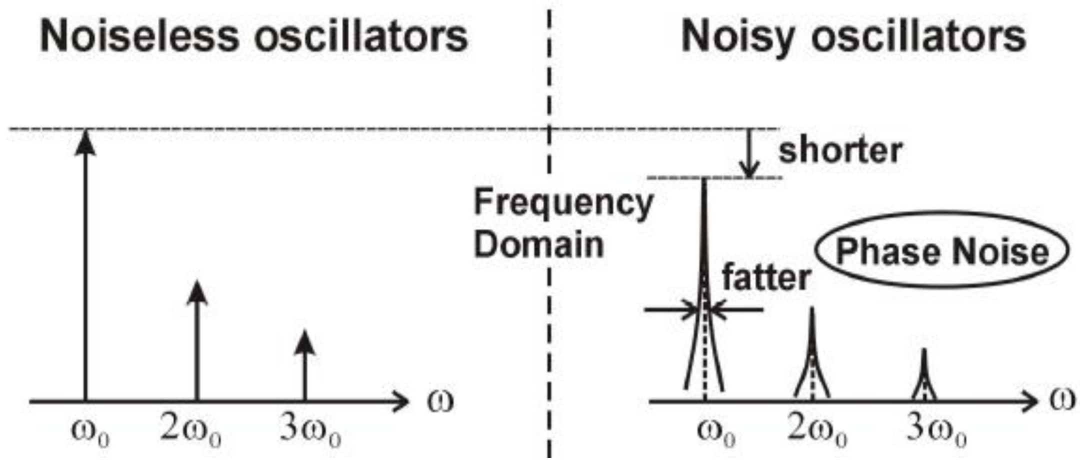


Fig 2.3 Effects of phase noise in oscillator frequency response

2.4 Frequency Offset

The term "frequency Offset" is used to define the ability of the oscillator to maintain a single fixed frequency as long as possible over a time interval. These deviations in frequency are caused due to variations in the values of circuit features (circuit components, transistor parameters, supply voltages, stray-capacitances, output load etc.) that determine the oscillator frequency.

It is known as deviation from the nominal output frequency i.e.

$$S = \frac{Fmeasured \ - Fnorminal}{Fnorminal}$$

Other factors responsible for drift in oscillator frequency are given below:

- If the operating point of the active device in the circuit is in the non-linear portion of its characteristics, there may be variations in the transistor parameters which, in turn, affect the oscillator frequency stability. So, the operating point, Q is selected such that the device works in the linear portion of its characteristics [4].
- When the circuit operates for a long time, the heat starts to build up. As a result, the values of the frequency determining components like resistors, inductors and capacitors change with temperature. Thus the transistor parameter values also tend to change. But, the change in the

values of R, L, and C will be slow and thus the change in oscillator frequency will also be slow.

- The other major factor responsible for deviation in frequency is variations in power supply (operating voltage applied to the active device). However, this problem can be overcome by using regulated power supply.

2.5 Power supply Noise [6]

The power supply noise is one of the sources of oscillator phase noise. It is more prominent and dominating in voltage controlled oscillators. Such noise typically appears as steps or impulses on the power supply of oscillators and it affects both frequency and phase of oscillators, causing jitter problems [8-9].

2.6 Phase versus Frequency curve

The oscillator oscillates until it satisfies the Barkhausen criterion of having zero degree phase of loop gain A(jω)B(iω). Now in addition to noise, spurs, and harmonics, oscillators have a problem with phase instability. Consider a model for the oscillator signal as follows:

$$V(t) = Acos[\omega_o t + \varphi_r(t)]$$

Where $\varphi_r(t)$ is a random process

Then

$$\omega(t) = \frac{d[\omega_o t + \varphi_r(t)]}{dt}$$

$$\omega(t) = \omega_o + \frac{d(\varphi_r(t))}{dt}$$

$$\omega(t) = \omega_o + \omega_r(t)$$

Where $\omega_r(t)$ is also a random process.

In other words, the frequency of an oscillator will vary slightly with time due to phase variations. But, if the change in frequency make the phase change in positive context such that Barkhausen criterion is not violated, then the phase changes will not have much effect on frequency change as both random process will counter-act and support each other. This frequency and phase relation is plotted for oscillators in terms of phase vs. frequency curve .And then slope of the phase vs. frequency curve tells about how much the unwanted change in frequency affects change in phase, so that oscillation frequency is not affected much. Greater the slope of the phase vs. frequency curve better will be the resistance in change in oscillation frequency due to unwanted frequency drifts.

References

[1] Edson .W. A., “Noise in Oscillators,” Proceedings of the IRE, Vol. 48, August 1960.

[2] Leeson D. B., “A Simple Model of Feedback Oscillator Noise Spectrum,” *Proceedings of the IEEE*, Vol. 54, February 1966.

[3]G. Sauvage, “Phase Noise in Oscillators: A Mathematical Analysis of Leeson’s Model,” IEEE Transactions on Instrumentation and Measurement, Vol. IM-26, No.4, December, 1977.

[4] http://www.circuitstoday.com/frequency-stability-of-oscillators

[5]. Mini-Circuits notes on VCO test methods from www.minicircuits.com

[6] Hui Zhou , Charles Nicholls , Thomas Kunz , Howard Schwartz, “Frequency Accuracy & Stability Dependencies of Crystal Oscillators”, Carleton University, Systems and Computer Engineering, Technical Report SCE-08-12, November 2008

[7] Jim Stiles,” Oscillator Stability.doc” The Univ. of Kansas Dept. of EECS 3/7/2005

[8]. T.Pialis and K. Phang, “Analysis of timing Jitter in Ring Oscillators Due to Power Supply Noise”, Circuits and Systems, ISCAS’03, Proceedings of the 2003 International Symposium. 2003

[9] Statek Technical Note 35, “An overview of oscillator jitter”, statek corporation, 2006-2007

Chapter-3

SECOND ORDER SINUSOIDAL OSCILLATORS

Various second order oscillator topologies are available in literature [2-4]. This chapter presents new topologies for second order sinusoidal oscillators based on OTRA. These are based on two principles i.e. placing a feedback loop around band pass filter and using tuned circuit.

3.1 Band Pass Filter based Second Order Sinusoidal Oscillator

In this section OTRA is used to design a band pass filter [2] (shown in Fig 3.1) which is then used in design of second order oscillator. One capacitor C_2 and one resistor R_2 is connected in parallel in feedback loop of OTRA between output V_0 and n terminal. Another resistor R_1 and capacitor C_1 is connected in series at p terminal of OTRA. The transfer function calculated between V_i and V_0 is of second order band pass filter and is shown below:

$$\frac{V_0}{V_i} = \frac{sC_1R_2}{(1+sC_1R_1)(1+sC_2R_2)}$$

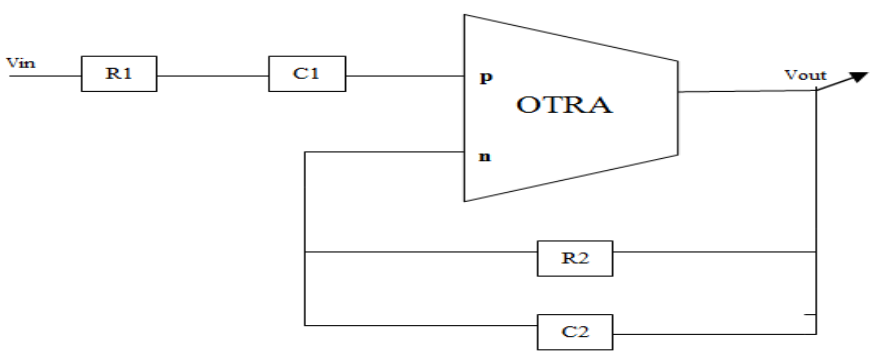


Fig 3.1 Second order band pass filter

The design topology of oscillator is shown in Fig3.2. It uses band pass filter designed using single OTRA. The output of band pass filter is connected to its input forming a close loop.

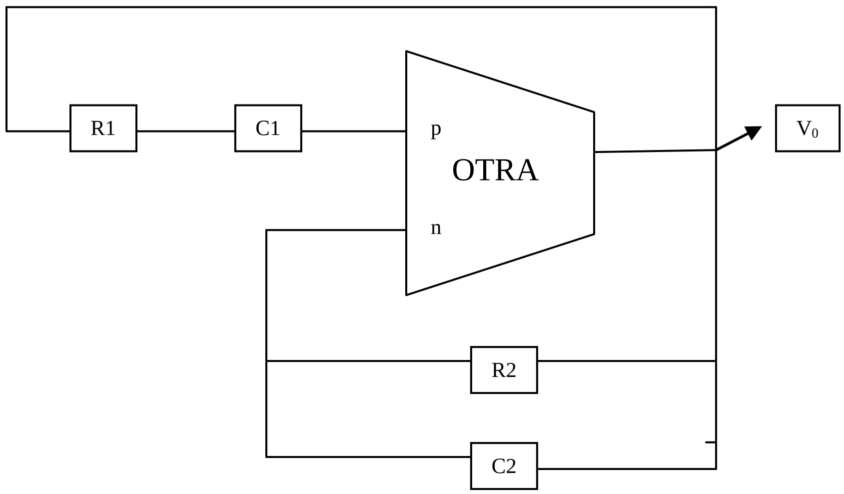


Fig 3.2 Proposed oscillator's Circuit 1

Routine analysis of the circuit of Fig. 3.2 results in following characteristic equation

$$s^2 + s\left(\frac{1}{C_2R_2} + \frac{1}{C_1R_1} - \frac{1}{C_2R_1}\right) + \frac{1}{C_1R_1C_2R_2} = 0 \qquad (3.1)$$

From this characteristic equation the condition of oscillation (CO) and frequency of oscillation (FO) can be found as

$$\text{FO:} \qquad f = \frac{1}{2\pi(C_2R_2C_1R_1)} \qquad (3.2)$$

$$\text{CO:} \qquad C_2R_2 = C_1(R_2 - R_1) \qquad (3.3)$$

Now, considering values of passive components, keeping in mind the condition of oscillation this circuit can be made to oscillate for the desired frequency using equation (3.2). For satisfying the Condition of oscillation, values of three passive elements is fixed and the fourth component's Value is decided using equation (3.3). Undamped sinusoidal oscillation can be observed at point marked as V_0 in Fig 3.2.

3.2 General LC oscillator design

General circuit for LC oscillator is shown in fig 3.3 where amplifier can be any amplifier among BJT, FET, OP-AMP etc.

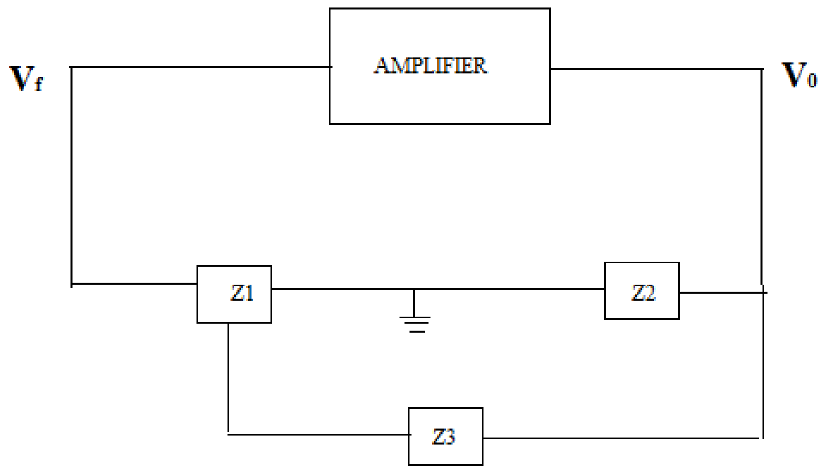


Fig 3.3 General LC oscillator circuit

V_0 is output of amplifier which is fed into network of impedances Z_1, Z_2 and Z_3. Routine Analyses of this circuit gives following equation:

$$V_f = \left(\frac{Z_1 V_0}{Z_1 + Z_3}\right)$$

$$\frac{V_f}{V_0} = \beta = \frac{Z_1}{Z_1 + Z_3} \quad (3.4)$$

Where β is the gain of impedance network

The General amplifier equivalent circuit along with network of impedances (shown in form of Z_L) can be represented as shown in fig 3.4.

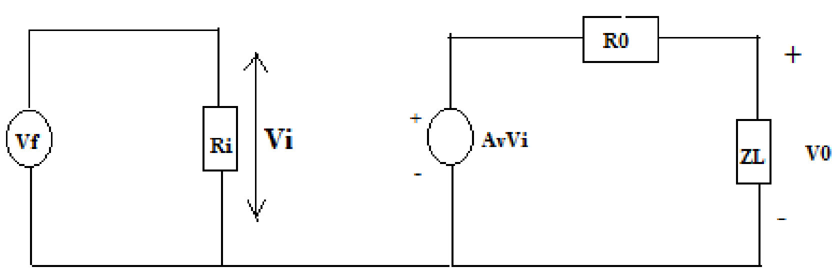


Fig 3.4 Equivalent circuit of amplifier along with impedances

From fig 3.4 $V_0 = \frac{Z_L}{Z_L + R_0} A_v V_i$ (3.5)

Where Z_L is the load impedance comprising of network shown in fig 3.4 and A_v is voltage gain of amplifier. Now, putting values of Z_L in equation (3.5), the overall Gain including load impedance (Z_L) is given as:

$$\frac{V_0}{V_i} = A_{V_{Z_L}} = A_v \frac{\frac{(Z_1+Z_3)Z_2}{(Z_1+Z_3+Z_2)}}{\frac{(Z_1+Z_3)Z_2}{(Z_1+Z_3+Z_2)} + R_0}$$

$$A_{V_{Z_L}} = A_v \frac{(Z_1+Z_3)Z_2}{(Z_1+Z_3)Z_2 + R_0(Z_1+Z_3+Z_2)} \quad (3.6)$$

Combining equation (3.4) and (3.6) and using $A_{V_{Z_L}}\beta = 1$, we get:

$$A_{V_{Z_L}}\beta = A_v \frac{(Z_1+Z_3)Z_2}{(Z_1+Z_3)Z_2 + R_0(Z_1+Z_3+Z_2)} \frac{Z_1}{Z_1+Z_3} = 1$$

Or

$$A_{V_{Z_L}}\beta = A_v \frac{Z_2 Z_1}{(Z_1+Z_3)Z_2 + R_0(Z_1+Z_3+Z_2)} = 1$$

Now, in LC oscillator circuits $Z_1 = iX_1,\ Z_2 = iX_2,\ Z_3 = iX_3$. Putting these values in above equation, we get:

$$\frac{-A_v X_1 X_2}{-(X_1+X_3)X_2 + R_0 j\,(X_1+X_2+X_3)} = 1 \quad (3.7)$$

Since loop gain $A_{V_{Z_L}}\beta$ of oscillation system is real value, imaginary term in equation (3.7) is zero which gives equation for calculating frequency of oscillation.

$$(X_1 + X_2 + X_3) = 0 \quad (3.8)$$

Using equation (3.8) in equation (3.7), we get:

$$\frac{A_v X_1 X_2}{(X_1+X_3)X_2} = 1$$

Or

$$\frac{A_v X_1 X_2}{-X_2\, X_2} = \frac{-A_v X_1}{X_2} = 1$$

$$|A_v| = \frac{X_2}{X_1} \quad (3.9)$$

Equation (3.9) is used for finding condition of oscillation.

3.2.1 OTRA Based Hartley Oscillator

The OTRA based Hartley oscillator is proposed in Fig 3.3. Here, OTRA provides a gain of $A_v = -\frac{R_2}{R_1}$ and the values of various impedances are selected as:

$Z_1 = iX_1 = j\omega L_1, Z_2 = iX_2 = j\omega L_1,\ Z_3 = iX_3 = -\frac{j}{\omega C_3}.$

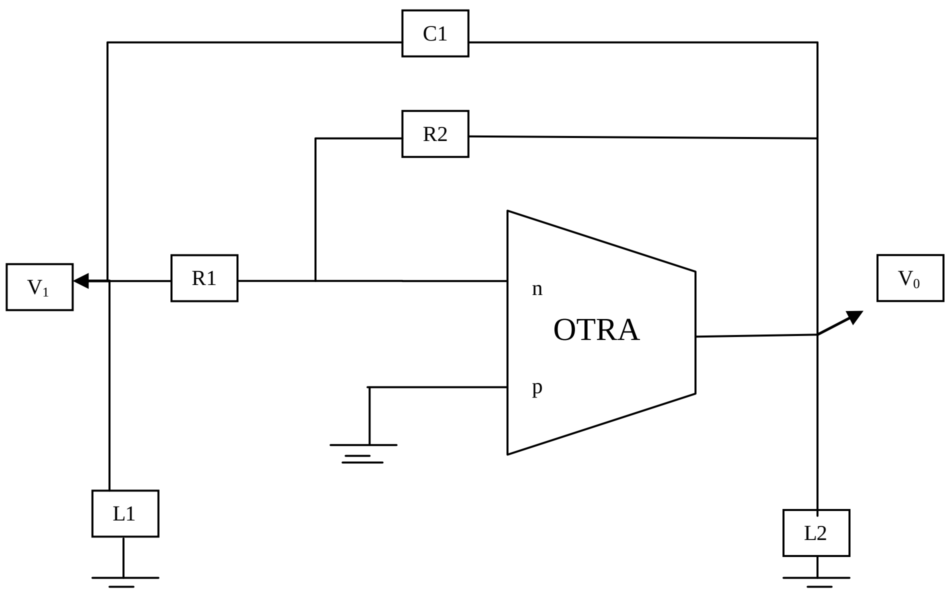


Fig. 3.5 OTRA based Hartley Oscillator

From equation (3.8) frequency of oscillation (FO) can be found as:

$$(\omega L_1 + \omega L_2) = \frac{1}{\omega C}$$

$$\omega^2 = \frac{1}{C(L_1+L_2)}$$

Or

$$f = \frac{1}{2\pi C(L_{eq})} \tag{3.10}$$

Where $L_{eq} = (L_1 + L_2)$

Using values of X_2 , X_1 and $A_v = -\frac{R_2}{R_1}$ in equation (3.9), the condition of is computed as

$\left|-\frac{R_2}{R_1}\right| = \frac{X_2}{X_1} = \frac{L_2}{L_1}$.

The relationship for the CO and FO of the proposed circuit are summarised below:

$$\text{FO:} \qquad f = \frac{1}{2\pi C L_{eq}} \tag{3.11}$$

Where

$$L_{eq} = L_1 + L_2$$

$$\text{CO:} \qquad \frac{R_2}{R_1} = \frac{L_2}{L_1} \tag{3.12}$$

The circuit can be made to oscillate at desired frequency by appropriate selection of components. For starting the oscillation as well as sustained oscillation, $\frac{R_2}{R_1} > \frac{L_2}{L_1}$ .The sinusoidal oscillation can be observed at two points i.e., at V_0 and V_1 marked in Fig 3.5.

3.2.2 OTRA Based Colpitts oscillator

The OTRA based Colpitts oscillator is proposed in Fig 3.6. Here, OTRA provides a gain of $A_v = -\frac{R_2}{R_1}$ and the values of various impedances are selected as:

$Z_1 = iX_1 = -\frac{j}{\omega C_1}, Z_2 = iX_2 = -\frac{j}{\omega C_2}, \; Z_3 = iX_3 = j\omega L_3.$

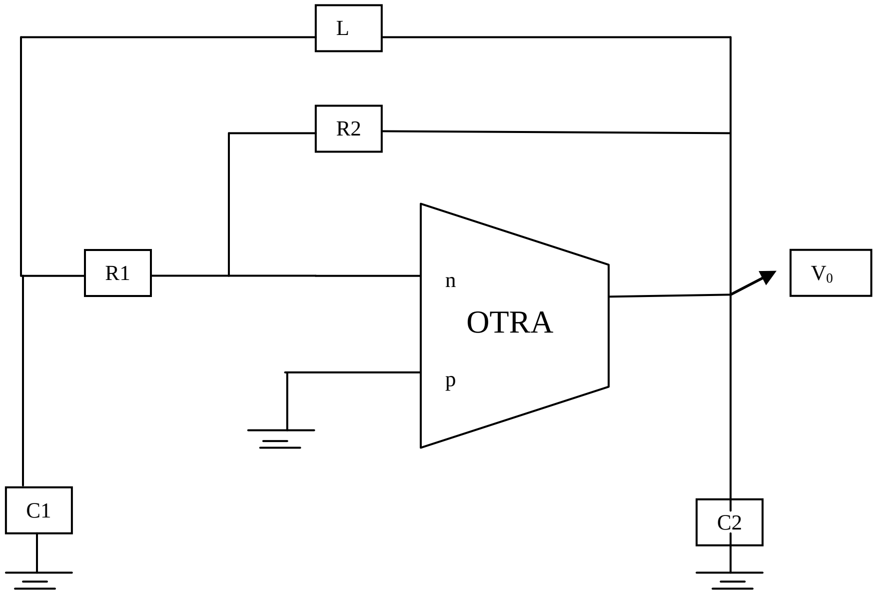


Fig3.6 OTRA based Colpitts Oscillator

From equation (3.8) frequency of oscillation (FO) can be found to be:

$$\omega L_3 - \frac{1}{\omega C_1} - \frac{1}{\omega C_2} = 0$$

$$\omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

Or

$$f = \frac{1}{2\pi L(C_{eq})} \tag{3.13}$$

Where $C_{eq} = (\frac{1}{C_1} + \frac{1}{C_2})$

Using values of X_2 , X_1 and $A_v = -\frac{R_2}{R_1}$ in equation (3.9), we get $\left|-\frac{R_2}{R_1}\right| = \frac{X_2}{X_1} = \frac{C_1}{C_2}$, which is condition of oscillation.

The relationship fir the CO and FO of the proposed circuit are summarised below:

$$\text{FO:} \qquad f = \frac{1}{2\pi L\, C_{eq}} \tag{3.14}$$

Where

$$C_{eq} = \frac{(C_1 C_2)}{(C_1 + C_2)}$$

$$\text{CO:} \qquad \frac{R_2}{R_1} = \frac{C_1}{C_2} \qquad (3.15)$$

Using above set of equations, the oscillator can be designed for desired frequency of oscillation. Generally, $\frac{R_2}{R_1} > \frac{C_1}{C_2}$ to start the oscillation. Sustained oscillation can be observed at point marked as V_0 in fig 3.6.

So, in this way second order oscillators were designed in this chapter. A close look at the frequency of oscillation and condition of oscillation of Hartley as well as Colpitts oscillator tells that these oscillators can be designed for fixed frequency as the feedback network involving inductance and capacitances is also responsible for providing 180 degree phase shift. In other words, condition of oscillation and frequency of oscillation are interdependent and hence, are not orthogonal. Accuracy of second order oscillators can be further improved by increasing the order of oscillator i.e., third order or higher order oscillators. Third order oscillators designs are mentioned in next chapter. Detailed schematic circuits with their transient and frequency responses are given in chapter 5.

References

[1] Sedra AS, Smith KC. Microelectronic circuits. 4th ed. Oxford University Press; 1998, p. 973–86

[2] Pandey.R, Pandey,N, kumar. R, solanki. G, “Novel OTRA based oscillator with non interactive control”, International Conference on Computer and communication technology (ICCCT),2010 Publication Year: 2010 , Page(s): 658 – 660

[3] Bothra M. ; pandey R.; pandey N., “Versatile voltage controlled relaxation oscillator using OTRA” 3rd international conference on ElectronicsComputer Technology (ICECT),2011, Publication Year: 2011 , Page(s): 394 – 398

[4] Pandey R., Bothra M. “Multiphase sinusoidal oscillators using Operational Trans-Resistance Amplifier”, IEEE Symposium on Industrial Electronics & Applications, 2009.ISIEA 2009, Publication Year: 2009 , Page(s): 371 - 376

[5] Minaei . S and Cicekoglu O, “New current-mode integrator, all-pass section and quadrature oscillator using only active elements,” 1st IEEE Int. Conf. Circuits and Systems for Communications, vol. 26-28, pp. 70– 73, 2002.

[6] Horng J. W., “Current-Mode quadrature oscillator with grounded capacitors and resistors using two DVCCs,” IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences, vol. E86-A, pp. 2152-2154, 2003.

[7] Chen J. J., Chen C.C., Tsao H. W, and. Liu S. I,“Current-mode oscillators using Single current follower,” Elec. Lett., vol. 27, pp. 2056- 2059, 1991.

[8] Kumwachara . K and Surakampontorn .W, “An integrable temperature insensitive gm–RC quadrature oscillator,” Int. J. Electronics, vol. 90, no. 1, pp.599-605, 2003.

[9] Serdijin,W.A; Mulder J; Van Der Woerd; Albert C.; Van Roermund,”Design of wide tunable translinear second order oscillators”, proceedings of 1997 IEEE International Symposium on Circuits And Systems1779.ISCAS. Publication Year.997,page(s) 829-832 Vol.2

[10] Serdijn, W.A; Mulder, J; Kouwenhouben,M.H.L; Van roermund,A.H.M,”A low-Voltage translinear second order quadrature oscillator”, proceedings of the 1999 IEEE international Symposium on Circuits and Systems,1999.ISCAS’99.Publication year 1999,page(s)701-704 vol2

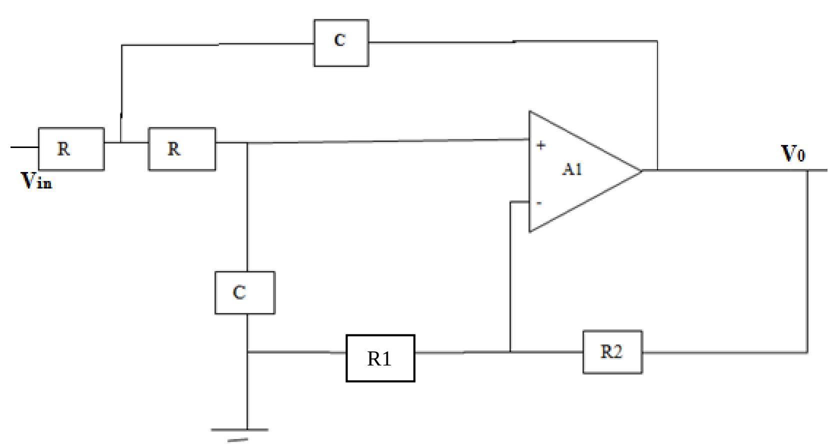
Chapter-4

THIRD ORDER SINUSOIDAL OSCILLATORS

In previous chapter second order oscillators were designed. The oscillators output were observed to be satisfactory but it is generally inferred that as the order of oscillator is increased, the accuracy of response is also improved. Hence, this chapter is dedicated to designing of third order oscillators. There are various circuit topologies available for making third order oscillators [5-10], most common of them is, two integrator loop oscillators realized using different active building blocks [4]. Three new topologies are presented in this chapter. Two of these structures are based on Sallen Key low pass filter whereas the third one is based on employing three lossy integrators and a gain block in feedback loop. The chapter first describes Sallen Key filter and oscillators based on it and then describes the third structure.

4.1 Opamp based Sallen Key Filter

Sallen key filter low pass filter circuit [2] is shown in Fig 4.1. The transfer function calculated between V_i and V_0 is given as



4.1 Sallen key filter's circuit diagram333

$$H(j\omega) = \frac{\frac{K}{R^2C^2}}{s^2+\frac{s}{RC}(3-K)+\frac{1}{R^2C^2}} \tag{4.1}$$

Where $K = 1 + \frac{R_2}{R_1}$

The Sallen Key filter is used as a core for designing third order oscillator.

4.1.1 Proposed Third order Sinusoidal Oscillator – Topology I

The proposed oscillator's circuit diagram is shown in Fig. 4.2. It uses Sallen key second order low pass filter of Fig. 4.1, lossy integrator and non-inverting gain stage forming a closed loop.

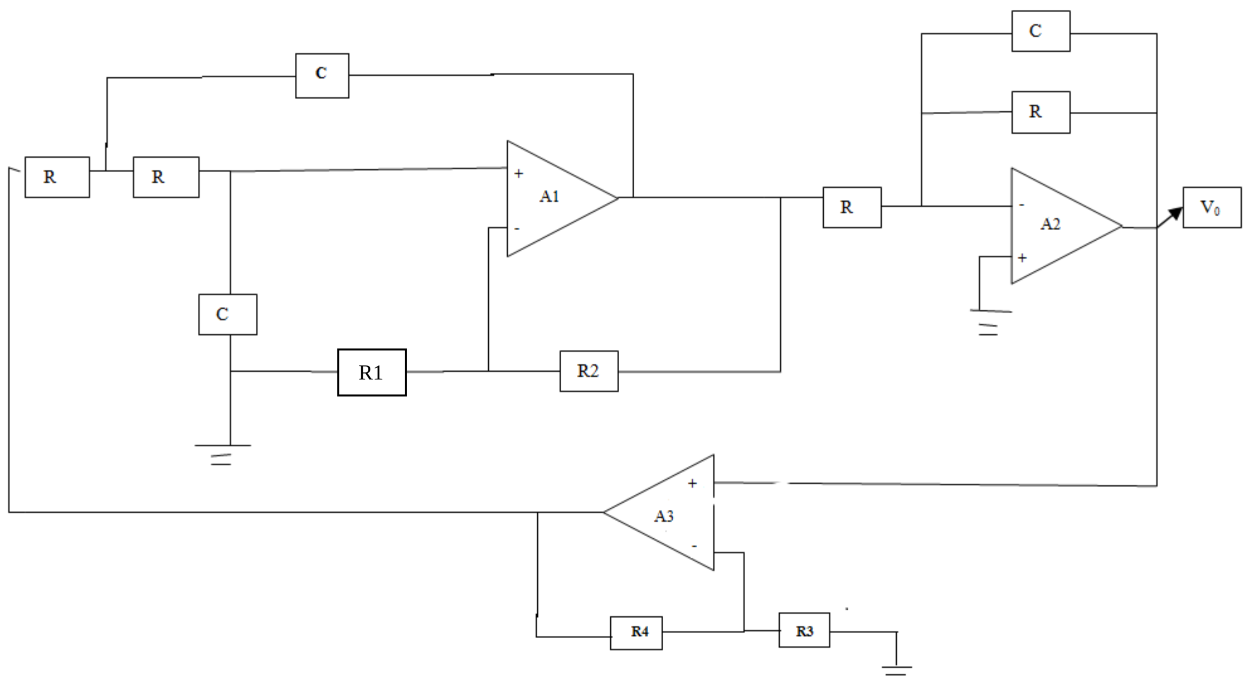


Fig4.2. Proposed third order Sinusoidal Oscillator – Topology I

Routine analysis of the circuit of Fig.4.2 results in following characteristic equation as

$$s^3 + \frac{s^2(4-K)}{RC} + \frac{s(4-K)}{R^2C^2} + \frac{(1+KK')}{R^3C^3} = 0 \tag{4.2}$$

Where

$K = \left(1 + \frac{R_2}{R_1}\right), K' = \left(1 + \frac{R_4}{R_3}\right)$

From this characteristic equation the condition of oscillation (CO) and frequency of oscillation (FO) can be found to be

$$\text{FO:} \qquad f = \frac{\sqrt{(4-\mathrm{K})}}{2\pi \mathrm{RC}} \tag{4.3}$$

$$\text{CO:} \qquad (4-K)^2 = (1+KK') \tag{4.4}$$

First the value of K' is fixed and then value of K is calculated using equation (4.4). Then, the values of remaining components are calculated according to desired frequency using equation (4.3). Oscillations are also observed at the output of A_1 with a phase difference with the waveform observed at output V_0. This phase difference is not exactly 90 degree due to integrator being lossy. In next section, loss- less integrator is used to obtain exact 90 degree phase difference.

4.1.2 Proposed Third order Sinusoidal Oscillator – Topology II

In previous section lossy integrator was used to design oscillator. The phase difference between sinusoidal waveforms at the output of amplifiers A_1 and A_2 in Fig 4.2 was not exactly 90 degree. A phase difference of 90 degree can be obtained by using loss-less integrator as shown in Fig.4.3. It uses Sallen key low pass filter and loss-less integrator in a closed loop. Undamped oscillations are observed at points marked as V_0 and V_1 which have quadrature phase relationship among them.

Routine analysis of the circuit of Fig.4.3 results in following characteristic equation as

$$s^3 + \frac{s^2(3-K)}{RC} + \frac{s}{R^2C^2} + \frac{K}{R^2C^3R_5} = 0 \tag{4.5}$$

Where

$$K = \left(1 + \frac{R_2}{R_1}\right) \tag{4.6}$$

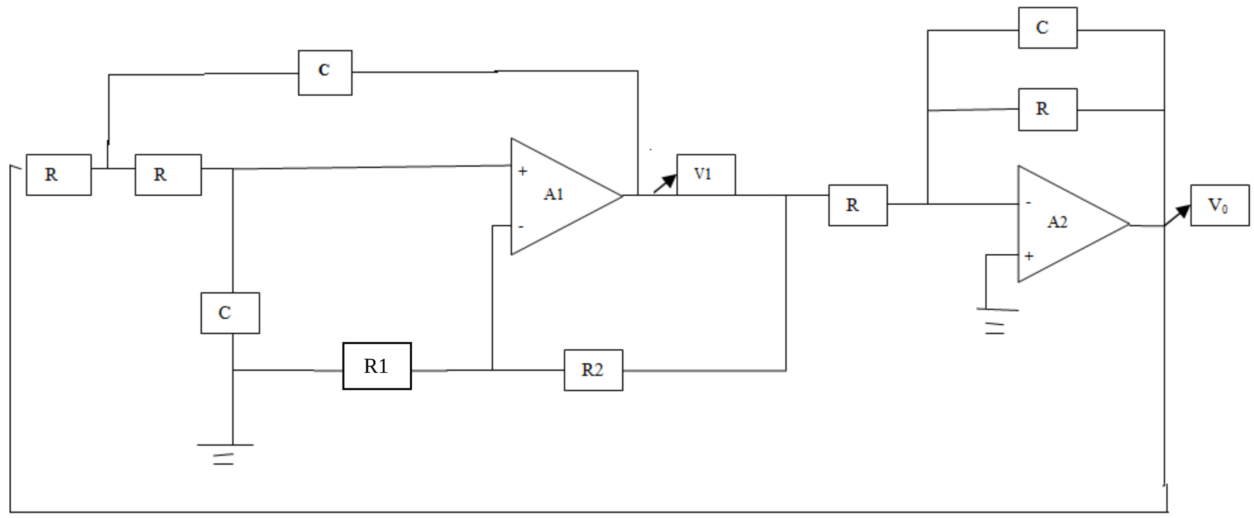


Fig 4.3 Proposed Third order Sinusoidal Oscillator – Topology II

From the characteristic equation of (4.6), the condition of oscillation (CO) and frequency of oscillation (FO) are computed as

$$\text{FO:} \qquad f = \frac{1}{2\pi RC} \qquad (4.7)$$

$$\text{CO:} \qquad R_5 = 2R \qquad (4.8)$$

Oscillator can be designed to oscillate at desired frequency by appropriate selection of components using above set of equations. Value of R and K is fixed and then R_5 is calculated using equation (4.8). After that value of C is decided as per the frequency of oscillation using equation (4.7).

4.2 OTRA based Third Order Sinusoidal Oscillator

This section contains sinusoidal oscillator based on topology in which three low pass filters are cascaded with gain stage in a loop to form third order oscillator. Active block being used is OTRA.

4.2.1 Proposed Third order Sinusoidal Oscillator – Topology III

Band pass filter using OTRA was used in designing of second order oscillator in previous chapter. In this section OTRA is used to design a low pass filter (shown in Fig 4.4) which is then used in design of third order oscillator. One capacitor C and one resistor R_2 is connected in parallel in feedback loop of OTRA between output V_0 and n terminal. And then another resistor R_1 is connected at p terminal of OTRA. The transfer function calculated between V_i and V_0 is of first order low pass filter and is shown below:

$$\frac{V_0}{V_i} = \frac{R_2/R_1}{1+sCR_2}$$

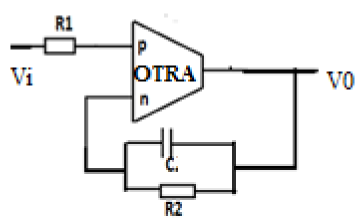


Fig 4.4 First order low pass filter

The design topology of oscillator is shown in Fig 4.5. It uses three OTRA based Low pass sections and one inverting gain stage of gain $K = \frac{-R_Y}{R_X}$ in a loop.

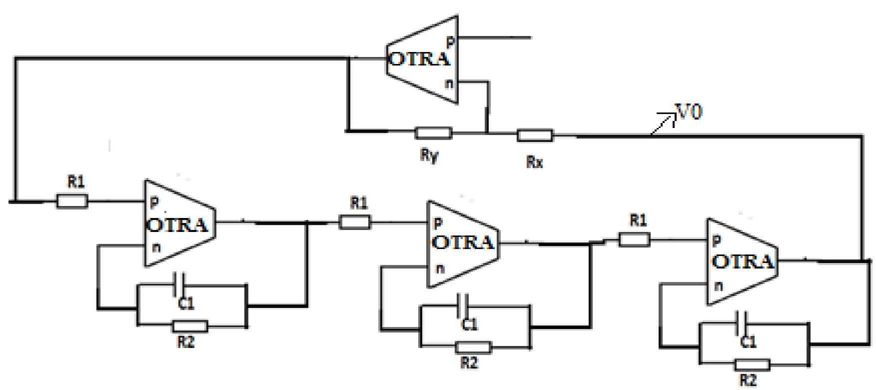


Fig.4.5. Proposed Third order Sinusoidal Oscillator – Topology III

Routine analysis of the circuit of Fig.4.5 results in following characteristic equation as

$$s^3 + 3\frac{s^2}{c_1 R_2} + 3\frac{s}{{R_1}^2{c_1}^2} + \frac{1}{{R_2}^3{c_1}^3} + \frac{R_Y}{{R_1}^3{c_1}^3 R_X} = 0 \tag{4.10}$$

From this characteristic equation the condition of oscillation (CO) and frequency of oscillation (FO) can be found to be

FO: $$f = \frac{\sqrt{3}}{2\pi \, \mathrm{C_1 R_2}} \tag{4.11}$$

CO: $$\left(\frac{2R_1}{R_2}\right)^3 = \frac{R_Y}{R_X} \tag{4.12}$$

First of all the value of $K = \frac{-R_Y}{R_X}$ is fixed and then the other components value is calculated keeping in mind the frequency and condition of oscillation using equation (4.12) and (4.11). Apart from node V_0 oscillation are also observed at the output of OTRA. So, in this way design of third order oscillators are given in this chapter. Detailed schematic circuits with their transient and frequency responses are given in next chapter.

References

[1] Sedra AS, Smith KC. Microelectronic circuits. 4th ed. Oxford University Press; 1998, p. 973–86

[2] Van Valkenburg M. Analog filter design. Holt, Rinehart and Winston; 1982, p. 549–69.

[3] Budak A. “Passive and active network analysis and synthesis”. Houghton Mifflin Company; 1974, p. 458–85.

[4] Ahmed M. Soliman, Two integrator loop quadrature oscillator:A review; Journal of Advanced Research (2013) 4, 1–11

[5] Ugur Cam, "A Novel single resistance controlled sinusoidal oscillator employing single operational transresistance amplifier", Analog integrated circuits and signal processing ,32, pp 183-186, 2002.

[6] Salama K. N. and Soliman A. M., "Novel Oscillators using the operational transresistance amplifier", Microelectronics journal, vol. 31, pp. 39-47, 2000.

[7] Maheshwari S., “Current-mode third order quadrature oscillator”, Circuits, Devices & Systems, IET Volume: 4, Issue: 3, Publication Year: 2010 , Page(s): 188 - 195

[8] Kumngern M., Chanwutitum J., “Single MCCCCTA-based mixed-mode third-order quadrature oscillator” Fourth International conference on Communications and Electronics (ICCE), 2012, Publication Year: 2012 , Page(s): 426 – 429

[9] Pandey.R, Pandey.S, Paul S.K, “MOS-C third order quarature oscillator using OTRA”, Third international conference on computer and communication technology (ICCCT), Publication Year: 2012 , Page(s): 77 – 80

[10] Koton J.,Herenscar . N, vrba .K, Metin .B, “Current and voltage mode third order quadrature oscillator”, 13th international conference on optimization of electrical and electronics equipments 2012, Publication Year: 2012 , Page(s): 1203 - 1206

Chapter-5

SIMULATIONS RESULTS

This chapter presents simulation results for the circuits proposed in chapter 3 and 4. The CMOS process parameters of 0.5um AGILENT technology are taken for verification of OTRA based oscillators and uA741 IC is used for OP-AMP based circuits. The outputs are shown in the form of graph of sinusoidal waveforms as well as their frequency response. The chapter is divided into different sections based on order of oscillator.

5.1 Functional Verification of Second Order Sinusoidal Oscillators

This section contains simulation results of second order oscillators using OTRA as an active block.

5.1.1 Second Order Sinusoidal Oscillators using Band Pass Filter

The schematic of OTRA based sinusoidal oscillator of Fig. 3.2 is depicted in Fig. 5.1. The oscillator is designed for 318.31 KHz frequency and the components values are chosen as

$$R_1 = 5K\Omega$$

$$R_2 = 10K\Omega$$

$$C_1 = 100pf$$

$$C_2 = 50pf$$

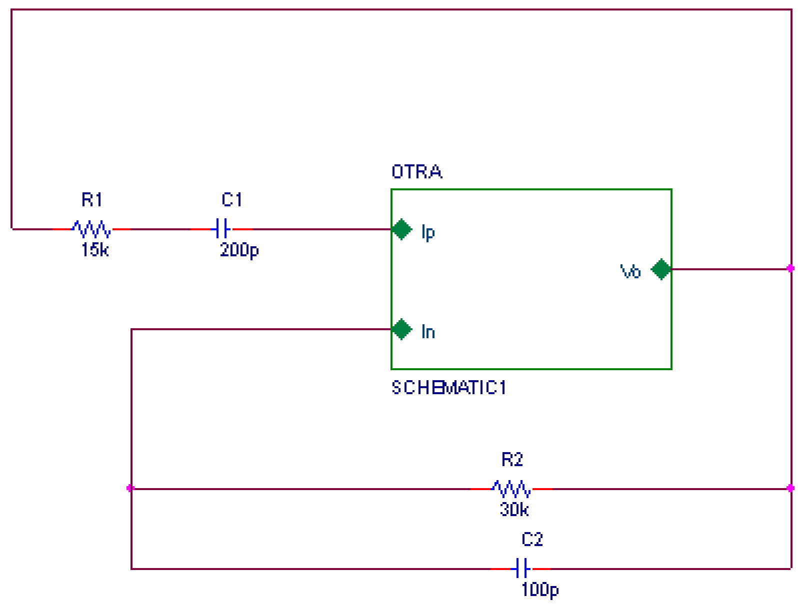


Fig 5.1 Schematic diagram of proposed oscillator 1

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.1 are shown in Fig.5.2 and Fig.5.3 respectively. The simulated value of FO was observed as 316.92 KHz which is near to the desired frequency of 318.31 KHz.

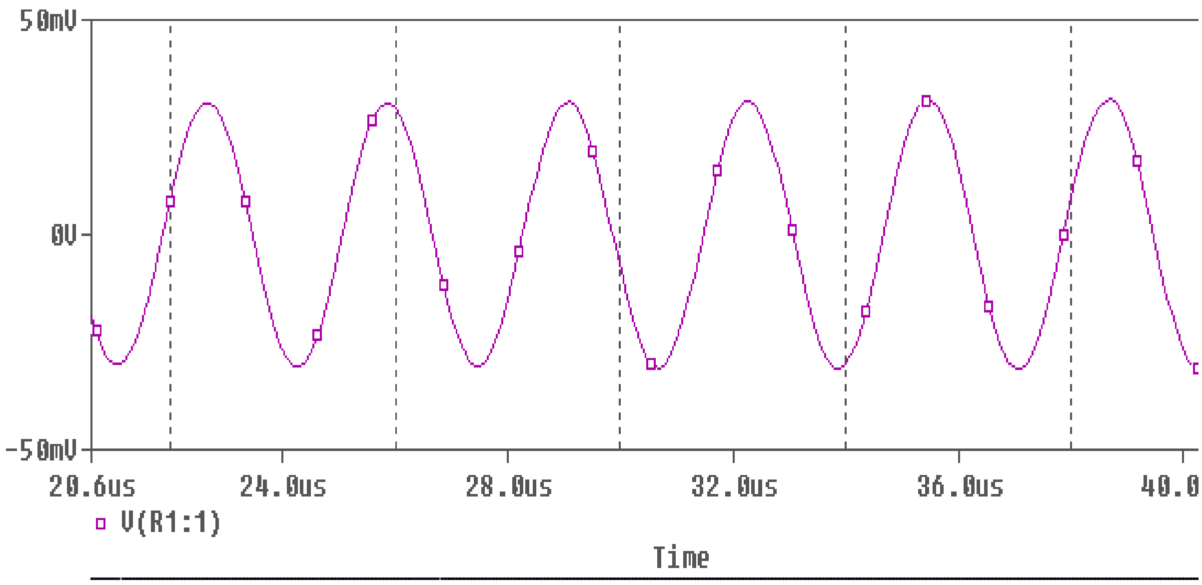


Fig 5.2 waveform diagram of proposed oscillator 1

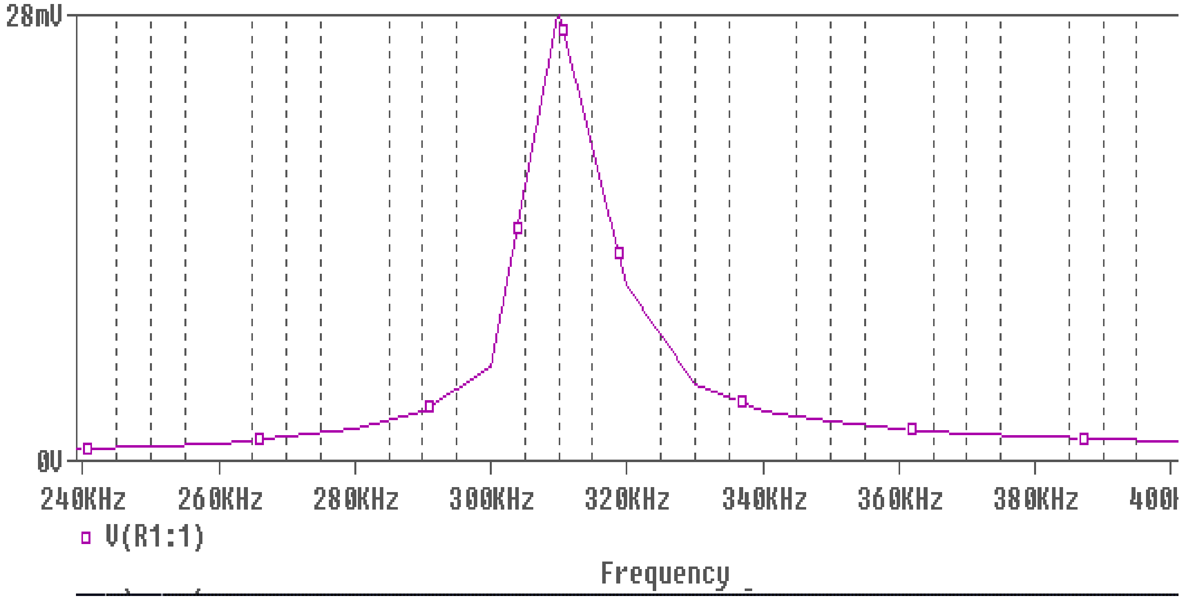


Fig 5.3 Frequency response diagram of proposed oscillator 1

5.1.2 OTRA based Hartley oscillator

The schematic of OTRA based sinusoidal oscillator of Fig. 3.5 is depicted in Fig. 5.4. The oscillator is designed for 339.26 KHz frequency and the components values are chosen as

$$R_1 = 75K\Omega$$

$$R_2 = 5K\Omega$$

$$L_1 = 10uH$$

$$L_2 = 100uH$$

$$C_1 = 2nf$$

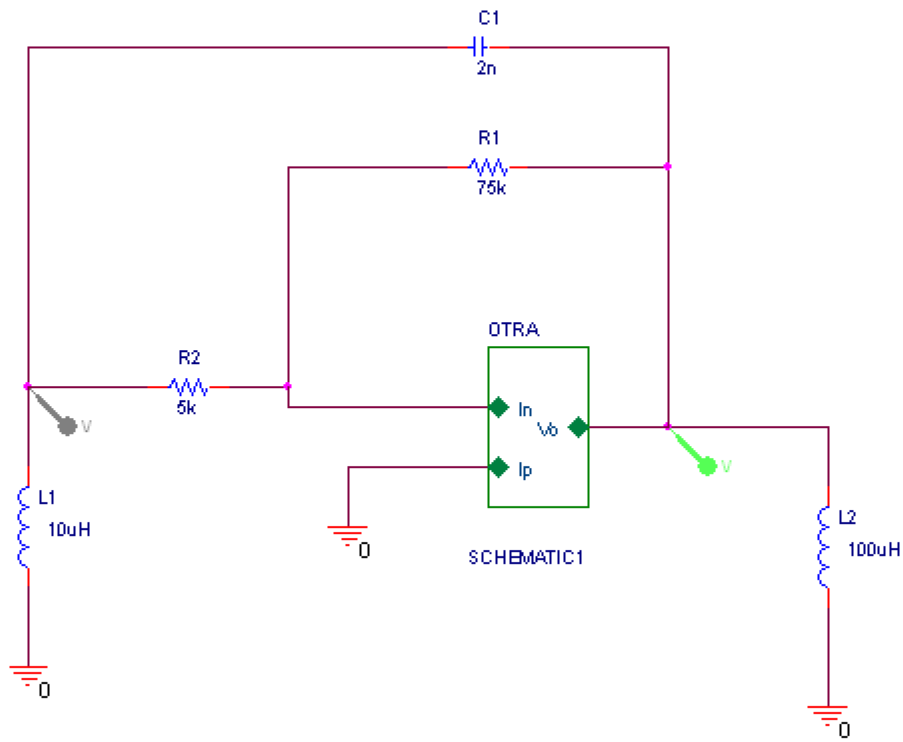


Fig 5.4 Schematic diagram of proposed oscillator 2

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.4 are shown in Fig.5.5 and Fig.5.6 respectively. The simulated value of FO was observed as 337.94 KHz which is near to the desired frequency of 339.26 KHz.

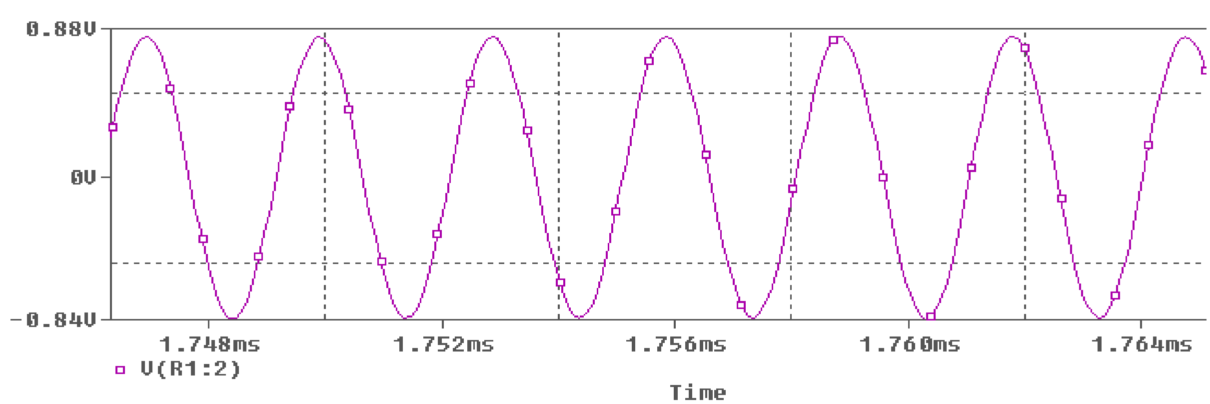


Fig 5.5 waveform diagram of proposed oscillator 2

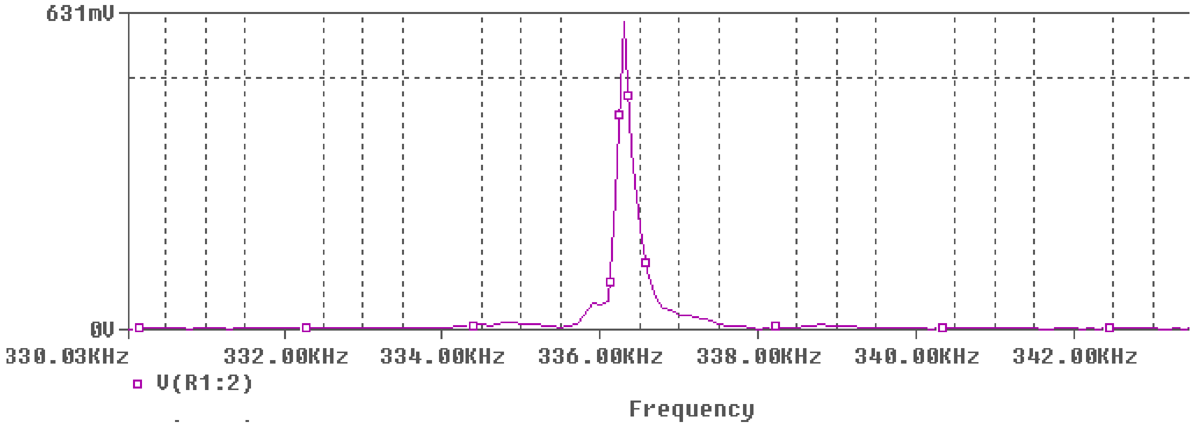


Fig 5.6 Frequency response diagram of proposed oscillator 2

5.1.3 OTRA based Colpitts oscillator

The schematic of OTRA based sinusoidal oscillator of Fig. 3.6 is depicted in Fig. 5.7. The oscillator is designed for 1.279 MHz frequency and the components values are chosen as

$$R_1 = 50K\Omega$$

$$R_2 = 5K\Omega$$

$$C_1 = 0.2nf$$

$$L = 86uH$$

$$C_2 = 1.8nf$$

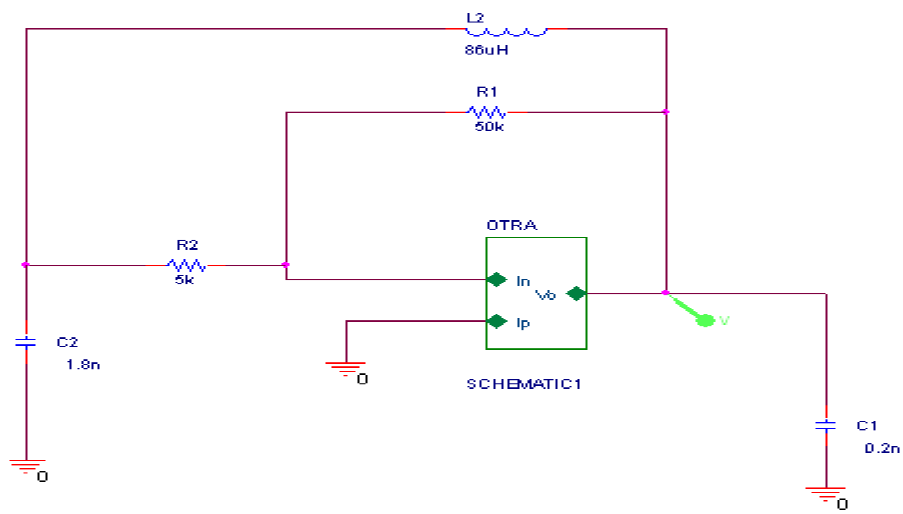


Fig 5.7 Schematic diagram of proposed oscillator 3

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.7 are shown in Fig.5.8 and Fig.5.9 respectively. The simulated value of FO was observed as 1.2357 MHz which is near to the desired frequency of 1.279MHz.

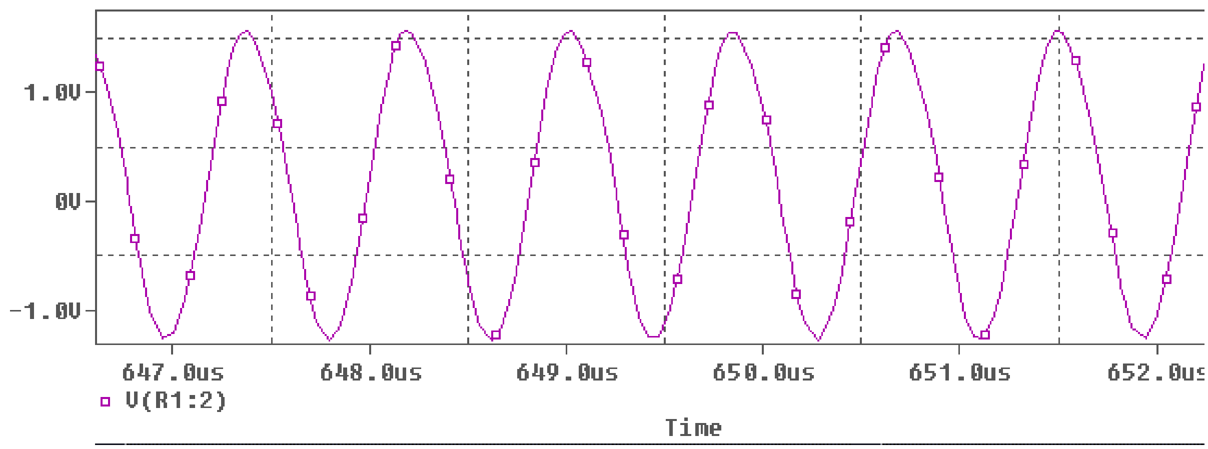


Fig 5.8 waveform diagram of proposed oscillator 3

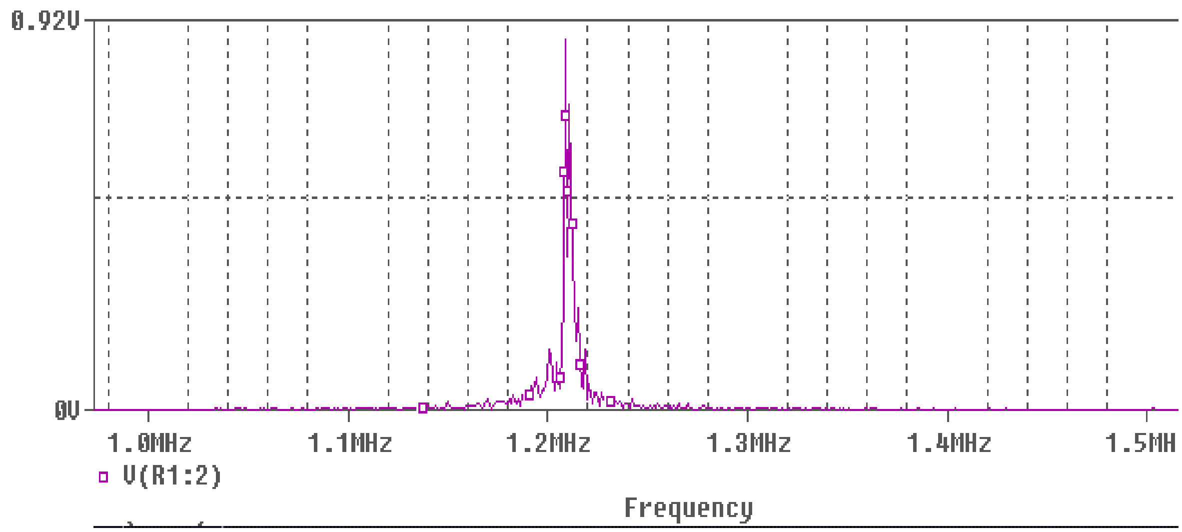


Fig 5.9 Frequency response diagram of proposed oscillator 3

5.2 Functional Verification of Third Order Sinusoidal Oscillators

This section contains simulation response of two third order oscillators using OP-AMP as an active block.

5.2.1 Proposed Third order Sinusoidal Oscillator – Topology I

The schematic of OP-AMP based sinusoidal oscillator of Fig. 4.2 is depicted in Fig. 5.10. The oscillator is designed for 6.43 KHz frequency and the components values are chosen as

$$R_2 = R_1 = 10K\Omega$$

$$R_3 = 10K\Omega$$

$$R_4 = 5K\Omega$$

$$R_5 = R_6 = R_7 = R_8 = R = 5K\Omega$$

$$C_1 = C_2 = C_4 = C = 7nf$$

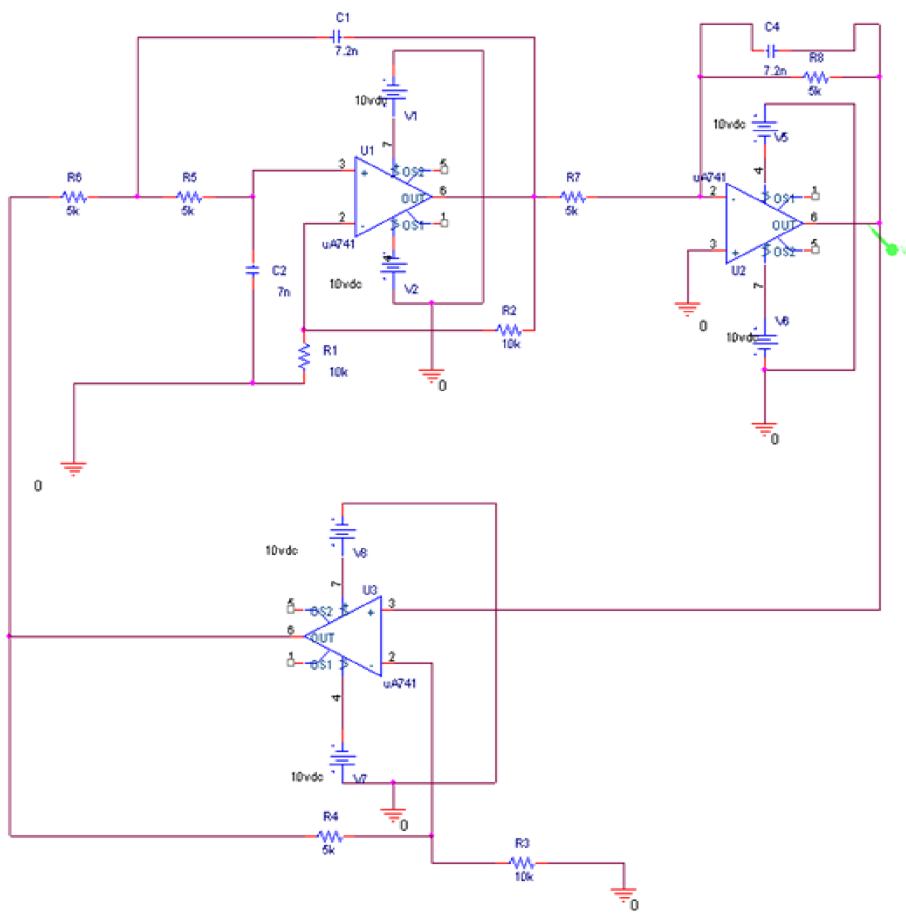


Fig 5.10 Schematic diagram of Proposed Third order Sinusoidal Oscillator – Topology I

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.10 are shown in Fig.5.11 and Fig.5.12 respectively. The simulated value of FO was observed as 6.45 KHz which is near to the desired frequency of 6.43 KHz.

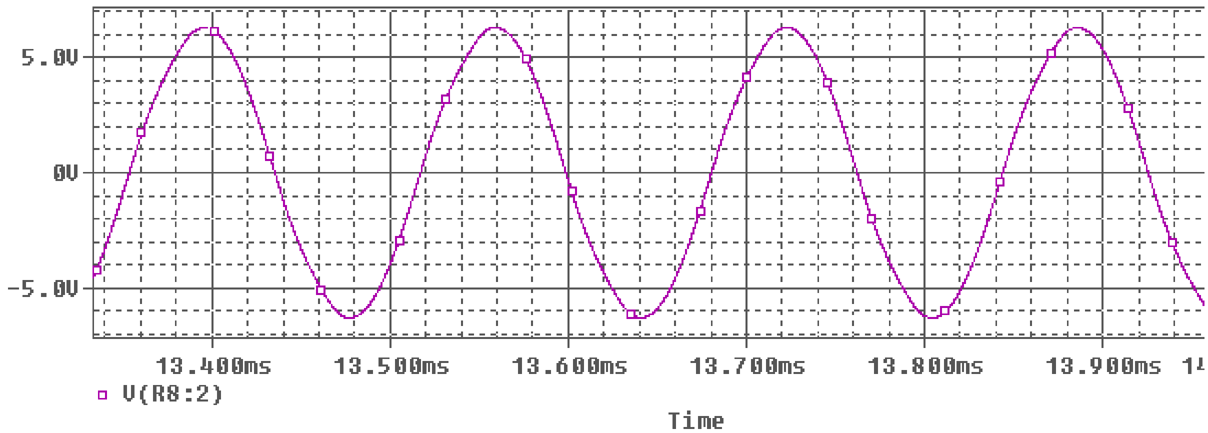


Fig 5.11 waveform diagram of proposed Third order Sinusoidal Oscillator – Topology I

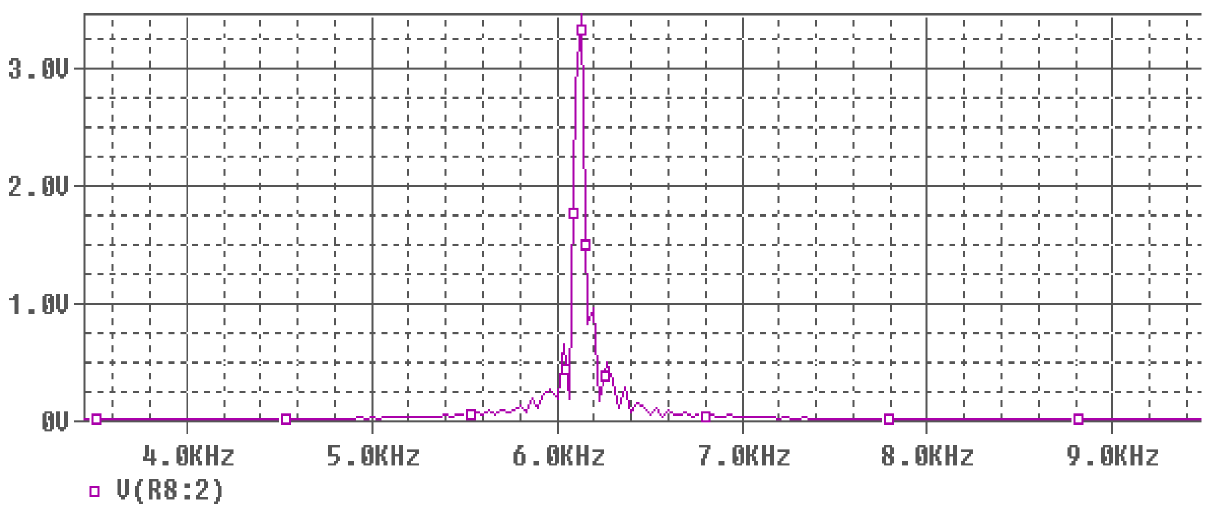


Fig 5.12.Frequency response diagram of Third order Sinusoidal Oscillator – Topology I

5.2.2 Proposed Third order Sinusoidal Oscillator – Topology II

The schematic of OP-AMP based sinusoidal oscillator of Fig. 4.3 is depicted in Fig. 5.13. The oscillator is designed for 1.989 KHz frequency and the components values are chosen as

$$R_2 = R_1 = 10K\Omega$$

$$R_3 = R_4 = R = 10K\Omega$$

$$R_5 = 20K\Omega$$

$$C_1 = C_2 = C_3 = C = 8nf$$

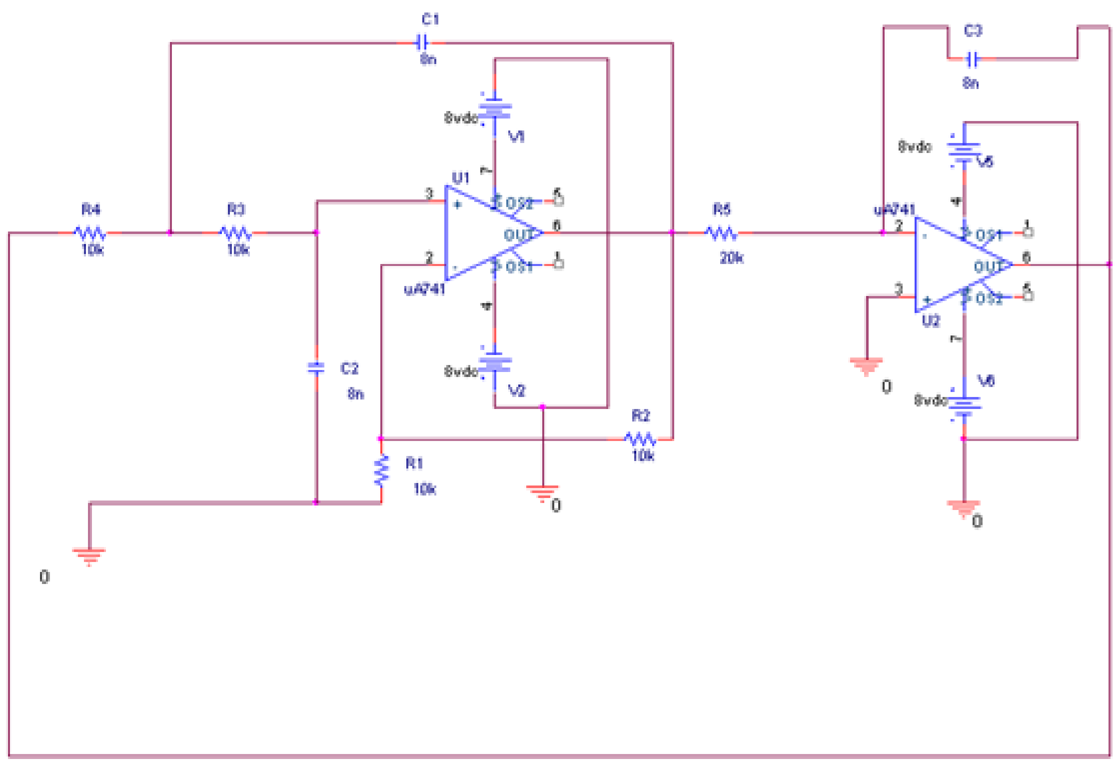


Fig 5.13 Schematic diagram of proposed Third order Sinusoidal Oscillator – Topology II

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.13 are shown in Fig.5.14 and Fig.5.15 respectively. The simulated value of FO was observed as 1.973 KHz which is near to the desired frequency of 1.989 KHz.

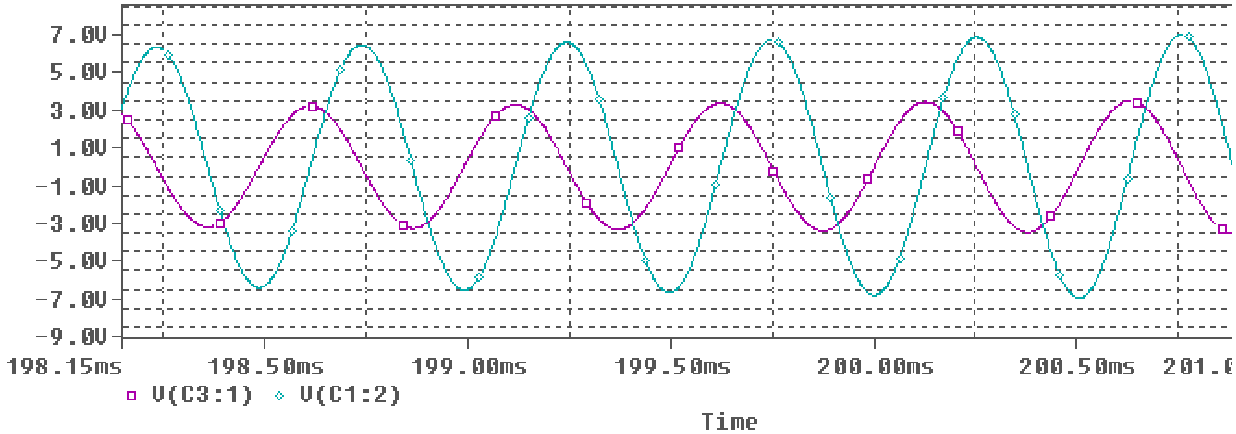


Fig 5.14 waveform diagram of proposed Third order Sinusoidal Oscillator – Topology II

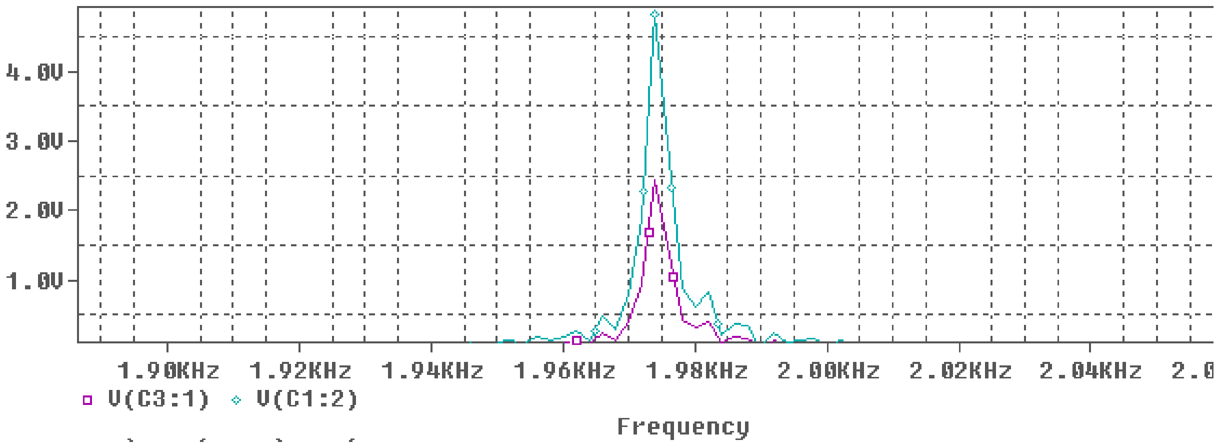


Fig 5.15 Frequency response diagram of proposed Third order Sinusoidal Oscillator – Topology II

5.2.3 Proposed Third order Sinusoidal Oscillator – Topology III

The schematic of OTRA based sinusoidal oscillator of Fig. 4.5 is depicted in Fig. 5.16. The oscillator is designed for 275.66 KHz frequency and the components values are chosen as

$$R_1 = R_3 = R_5 = 10K\Omega$$

$$R_2 = R_4 = R_6 = 10K\Omega$$

$$R_8 = 8K\Omega$$

$$R_7 = 1K\Omega$$

$$C_1 = C_2 = C_3 = C = 100pf$$

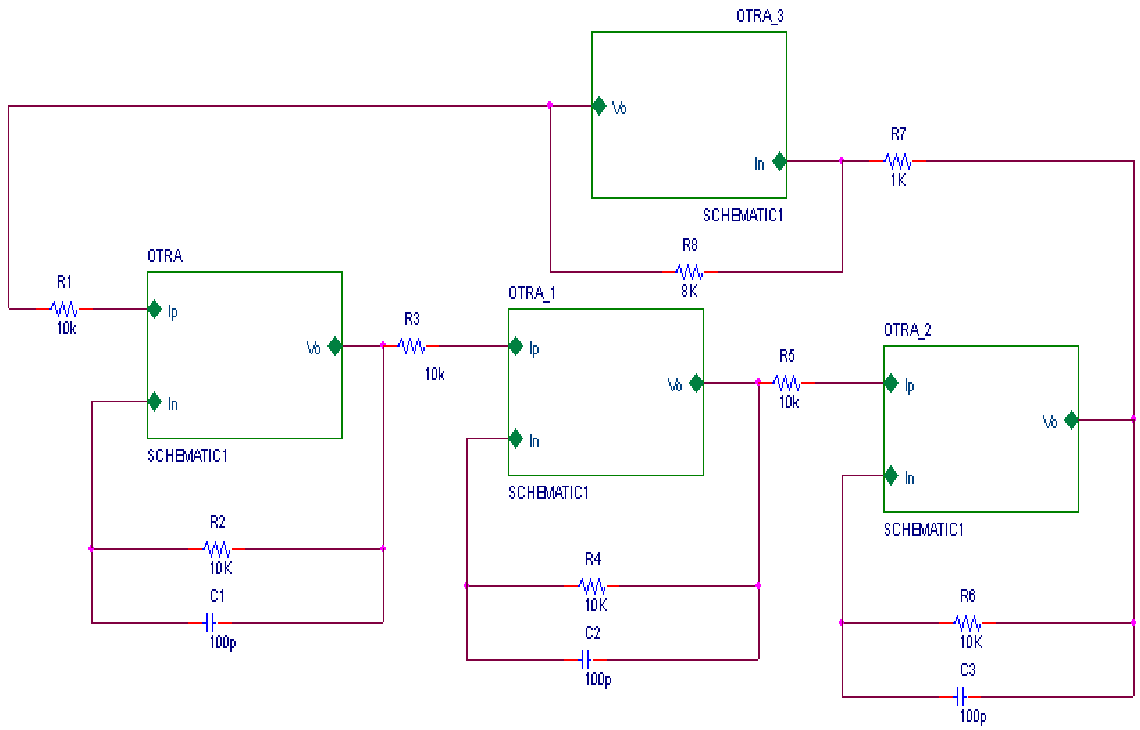


Fig 5.16 Schematic diagram of proposed Third order Sinusoidal Oscillator – Topology III

The simulations are carried out with supply voltages of ±1.5V. The simulated transient output and corresponding frequency spectrum for Fig.5.16 are shown in Fig.5.17 and Fig.5.18 respectively. The simulated value of FO was observed as 273.54 KHz which is near to the desired frequency of 275.66 KHz.

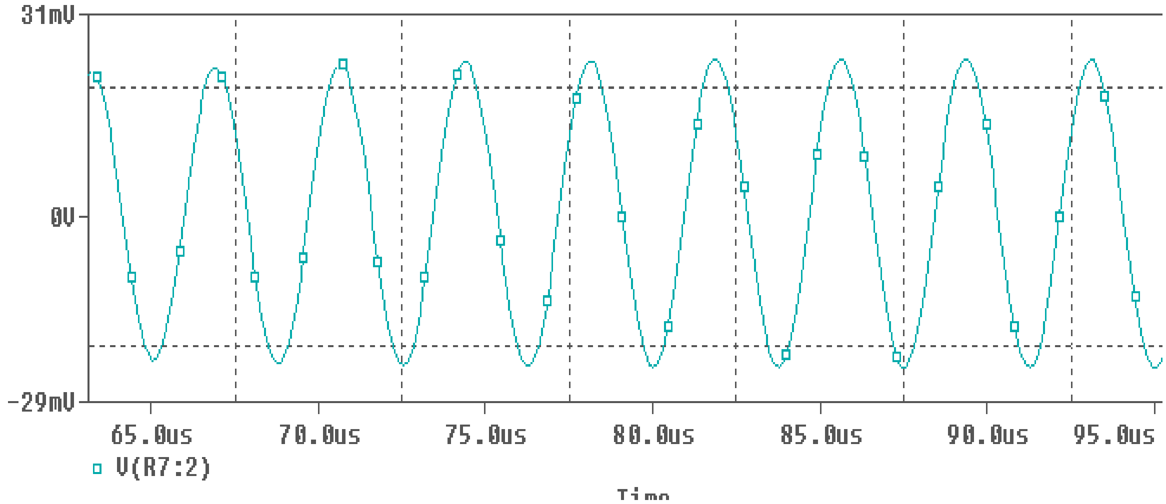


Fig 5.17 waveform diagram of proposed Third order Sinusoidal Oscillator – Topology III

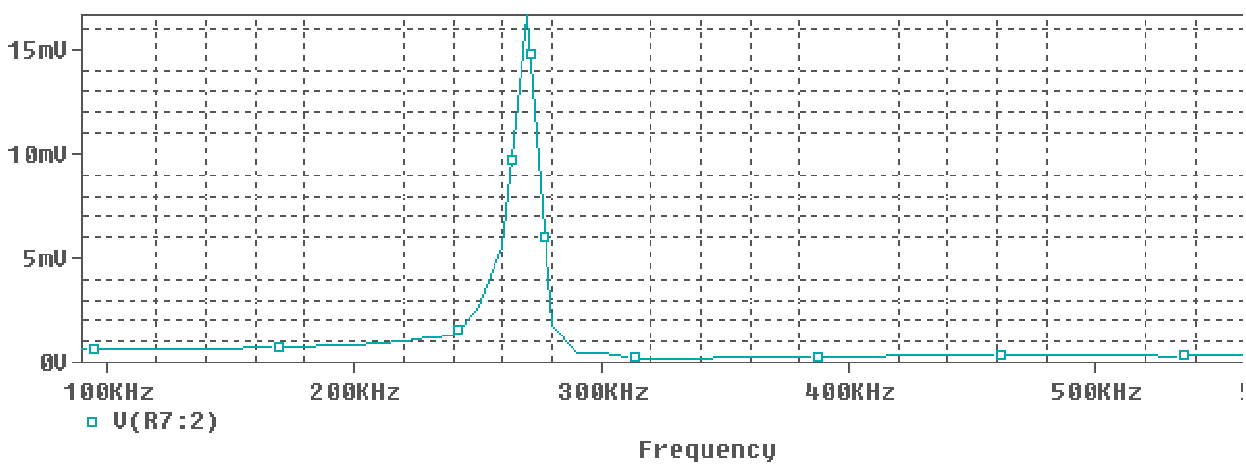


Fig 5.18 Frequency response diagram of proposed Third order Sinusoidal Oscillator – Topology III

So, in this way oscillator are simulated and their responses are verified. In next chapter, performance parameters (described in chapter 2) of these oscillators are evaluated.

Chapter-6

Performance Parameters Analyses of Oscillators

This chapter analyses the different proposed oscillators on the basis of oscillators parameters described in the chapter 2 and then compare the different circuits. The chapter is divided into different sections based on type of analyses i.e. Phase noise analyses, THD analyses with frequency variation and calculation of frequency offset for different order of oscillators. An analysis of oscillators is done by using mathematical formulas in chapter 2. Then, the THD is also calculated at different oscillations frequencies. The plots of THD vs. Frequency for the circuits are also plotted. Frequency offset is calculated for all the circuits.

6.1 Phase Noise Analyses

This section contains phase noise analyses of third order oscillators using mathematical formulas in chapter 2.

6.1.1 Third Order Sinusoidal Oscillators using OP-AMP

This section contains Phase Noise analyses of two third order oscillators using OP-AMP as an active block.

6.1.1.1 Third order Sinusoidal Oscillator – Topology I

The transfer function for the proposed oscillator can be written as follows

$$H(i\omega) = \left(\frac{\frac{KG^2}{C^2}}{s^2+\frac{sG\,(3-K)}{C}+\frac{G^2}{C^2}}\right)\left(\frac{1}{1+\frac{s}{\frac{G}{C}}}\right) \qquad (6.1)$$

Where

$K = \left(1+\frac{R_2}{R_1}\right)$

Keeping K=2, we get

$$H(i\omega) = \left(\frac{\frac{2G^2}{C^2}}{s^2+\frac{sG\,(3-2)}{C}+\frac{G^2}{C^2}}\right)\left(\frac{1}{1+\frac{s}{\frac{G}{C}}}\right) \tag{6.2}$$

We know that $\omega_{i=}G/C$ hence, substituting it into equation (6.2) we get

$$H(i\omega) = \left(\frac{1}{\left(-\left(\frac{\omega}{\omega_i}\right)^2+\frac{j}{2\sqrt{2}}\left(\frac{\omega}{\omega_i}\right)+\frac{1}{2}\right)}\right)\left(\frac{1}{1+j\frac{\omega}{\omega_i}}\right)$$

Or

$$H(i\omega) = \left(\frac{1}{\frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2+i2\zeta\frac{\omega}{\omega_i}}\right)\left(\frac{1}{1+j\frac{\omega}{\omega_i}}\right)$$

Where $\zeta = \frac{1}{2\sqrt{2}}$, $\mu = 1$ Then,

$$H(j\omega) = \left(\frac{1}{\frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2[1+2\zeta]+j\frac{\omega}{\omega_i}\left[\zeta+\frac{1}{\left\{\frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2\right\}}\right]}\right) \tag{6.3}$$

Let $X = \frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2[1+2\zeta]$ and $Y = \frac{\omega}{\omega_i}\left[\zeta+\frac{1}{\left\{\frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2\right\}}\right]$ from equation (6.3) we get

$$H(j\omega) = \left(\frac{1}{X+jY}\right) \tag{6.4}$$

Putting equation (6.4) into equation (2.3), we get

$$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{(X^2+Y^2)}{((1-X^2)^2+Y^2)} \tag{6.5}$$

Table 6.1 lists the values of (6.5) with $\left(\frac{\omega}{\omega_i}\right)$ ranging from 0.1 to 1.5 and corresponding graph is plotted in Fig. 6.1.

Table 6.1 Phase noise Analyses for proposed third order oscillator –Topology I

$\left(\frac{\omega}{\omega_i}\right)$	$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{(X^2+Y^2)}{((1-X^2)^2+Y^2)}$
0.1	17.37797
0.2	6.67039
0.3	2.975293
0.4	1.457388
0.5	0.737256
0.6	0.376608
0.7	0.207047
0.8	0.151
0.9	0.16352
1.0	0.221749
1.1	0.300212
1.2	0.3866
1.3	0.471716
1.4	0.550277
1.5	0.619832

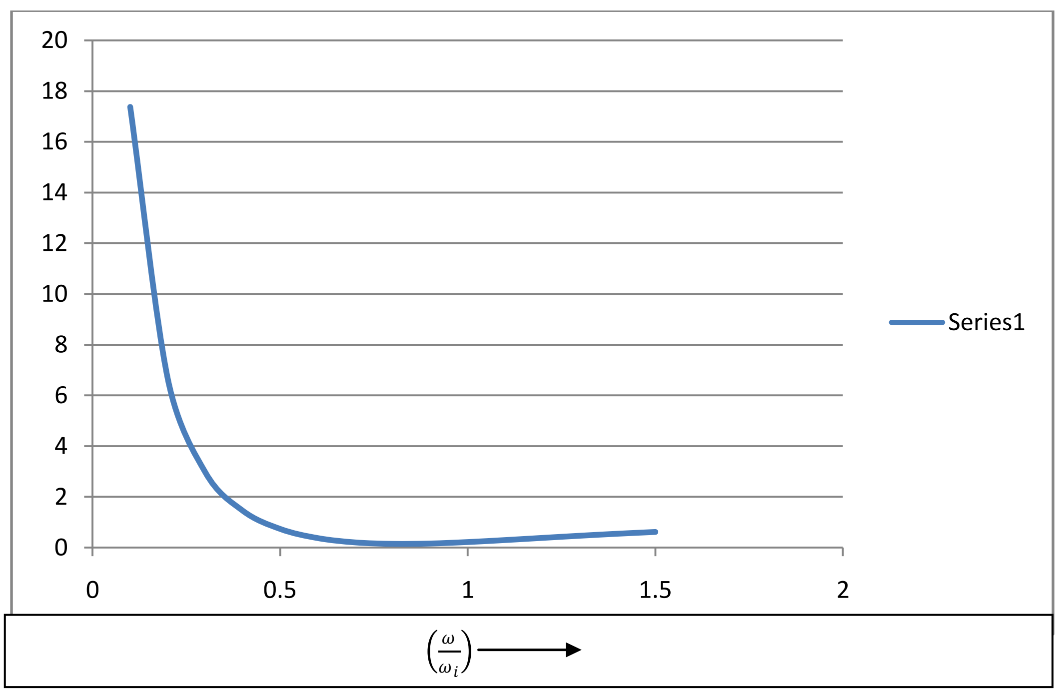


Fig6.1 Phase noise Plot for proposed third order oscillator-Topology I

It can be observed from Fig. 6.1 that phase noise is high at frequencies less than the oscillation frequency and tend to decrease close to the oscillation frequency and reached down to Zero at oscillation frequency, Afterwards, it varies very slowly and remains near to zero most of the time.

6.1.1.2 Third Order Sinusoidal Quadrature Oscillators using sallen key low pass filter and loss-less Integrator

The transfer function for the proposed oscillator can be written as follows

$$H(s) = \left(\frac{\frac{KG^2}{C^2}}{S^2+\frac{SG\,(3-K)}{C}+\frac{G^2}{C^2}}\right)\left(\frac{1}{SCR}\right) \quad (6.6)$$

Where

$$K = \left(1+\frac{R_2}{R_1}\right)$$

Keeping K=2, we get

$$H(s) = \left(\frac{\frac{2G^2}{C^2}}{S^2+\frac{SG\,(3-2)}{C}+\frac{G^2}{C^2}}\right)\left(\frac{1}{SCR_5}\right) \quad (6.7)$$

We know that $\omega_{i=}G/C$ hence, substituting it into equation (6.7) we get

$$H(i\omega) = \left(\frac{1}{\left(-\frac{1}{2}\left(\frac{\omega}{\omega_i}\right)^2+j\frac{1}{2}\left(\frac{\omega}{\omega_i}\right)+\frac{1}{2}\right)}\right)\left(\frac{1}{j\frac{\omega}{\omega_i}\frac{R_5}{R}}\right) \quad (6.8)$$

Using $R_5 = 2R$ in equation (6.8)

$$H(i\omega) = \left(\frac{1}{\frac{1}{2}-\left(\frac{\omega}{\omega_i}\right)^2+i2\zeta\frac{\omega}{\omega_i}}\right)\left(\frac{1}{j2\frac{\omega}{\omega_i}}\right)$$

Where $\zeta = \frac{1}{4}$, $\mu = 1$ Then,

$$H(j\omega) = \left(\frac{1}{-4\zeta\left(\frac{\omega}{\omega_i}\right)^2+j\frac{\omega}{\omega_i}\left[1-\frac{\omega}{\omega_i}\right]}\right) \quad (6.9)$$

Let $X = -4\zeta\left(\frac{\omega}{\omega_i}\right)^2$, $Y = \frac{\omega}{\omega_i}\left[1-\frac{\omega}{\omega_i}\right]$ then,

$H(j\omega) = \left(\frac{1}{X+jY}\right)$

(6.10)

Putting equation (6.10) into equation (2.3), we get

$$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{(X^2+Y^2)}{((1-X^2)^2+Y^2)} \quad (6.11)$$

Or

$$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{(\left(\frac{\omega}{\omega_i}\right)^4+\left(\frac{\omega}{\omega_i}\right)^2\left(1-\left(\frac{\omega}{\omega_i}\right)\right)^2)}{\left(1+\left(\frac{\omega}{\omega_i}\right)^2\right)^2+\left(\frac{\omega}{\omega_i}\right)^2\left(1-\left(\frac{\omega}{\omega_i}\right)\right)^2} \quad (6.12)$$

Now evaluating equation (6.12) with $\left(\frac{\omega}{\omega_i}\right)$ we get following table:

Table 6.2 Phase noise analysis for proposed third order oscillator-Topology II

$\left(\frac{\omega}{\omega_i}\right)$	$[(H(j\omega)-1)(H^*(j\omega)-1)]^{-1} = \frac{(\left(\frac{\omega}{\omega_i}\right)^4+\left(\frac{\omega}{\omega_i}\right)^2\left(1-\left(\frac{\omega}{\omega_i}\right)\right)^2)}{\left(1+\left(\frac{\omega}{\omega_i}\right)^2\right)^2+\left(\frac{\omega}{\omega_i}\right)^2\left(1-\left(\frac{\omega}{\omega_i}\right)\right)^2}$
0.1	0.007975
0.2	0.024566
0.3	0.042363
0.4	0.059293
0.5	0.076923
0.6	0.098154
0.7	0.125519
0.8	0.160283
0.9	0.202241
1.0	0.25
1.1	0.301499
1.2	0.354538
1.3	0.407163
1.4	0.457863
1.5	0.505618

Plotting table 6.2 we get

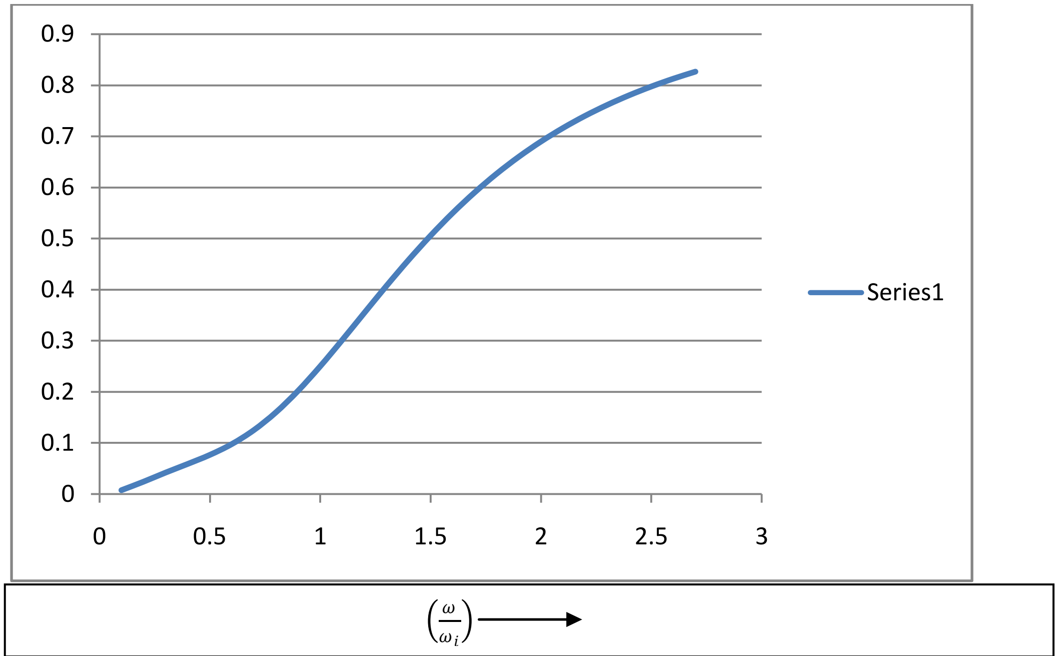


Fig 6.2 Phase noise plot for proposed third order oscillator-Topology II

It can be observed from graph that phase noise is less at frequencies less than the oscillation frequency and tend to rise as we move near to the oscillation frequency and it further rises till the frequency gets equal to three times the oscillation frequency. Afterwards, it's rising slope decreases.

6.1.2 Third Order Sinusoidal Oscillators using OTRA

This section contains Phase Noise analyses of a third order oscillators using OTRA as an active block.

6.1.2.1 Third Order Sinusoidal Oscillators-Topology I

The transfer function for the third order Low pass filter used in proposed oscillator can be written as follows:

$$H(j\omega) = \left(\frac{1}{1-\left(\frac{\omega}{\omega_i}\right)^2-\frac{j2\zeta\omega}{\omega_i}}\right)\left(\frac{1}{1+i\omega_3}\right) \qquad (6.13)$$

Where$\zeta = 1, \omega_i = \frac{1}{R_2 C_2}, \omega_3 = \omega_i$

Putting equation (6.13) into equation (2.8) and solving we get

$$[(H(j\omega) - 1)(H^*(j\omega) - 1)]^{-1} = 1 + \frac{\left(1-6\left(\frac{\omega}{\omega_i}\right)^2\right)}{\left(\frac{\omega}{\omega_i}\right)^6 + 3\left(\frac{\omega}{\omega_i}\right)^4 + 9\left(\frac{\omega}{\omega_i}\right)^2} \qquad (6.14)$$

Then, equation (6.14) is plotted for different values of $\frac{\omega}{\omega_i}$ varied from 0.1 to 1.5 and tabled below:

Table 6.3 Phase noise Analysis for proposed third order oscillator Topology III

$\left(\frac{\omega}{\omega_i}\right)$	$[(H(j\omega) - 1)(H^*(j\omega) - 1)]^{-1} = 1 + \frac{\left(1-6\left(\frac{\omega}{\omega_i}\right)^2\right)}{\left(\frac{\omega}{\omega_i}\right)^6 + 3\left(\frac{\omega}{\omega_i}\right)^4 + 9\left(\frac{\omega}{\omega_i}\right)^2}$
0.1	11.4085
0.2	3.08296
0.3	1.550879
0.4	1.0263
0.5	0.737256
0.6	0.68439
0.7	0.63033
0.8	0.60832
0.9	0.6057
1.0	0.6153
1.1	0.6329
1.2	0.65534
1.3	0.6804
1.4	0.7067
1.5	0.73306

Now, plotting equation (6.14) on Y-axis and $\frac{\omega}{\omega_i}$ on X-axis, we get following curve

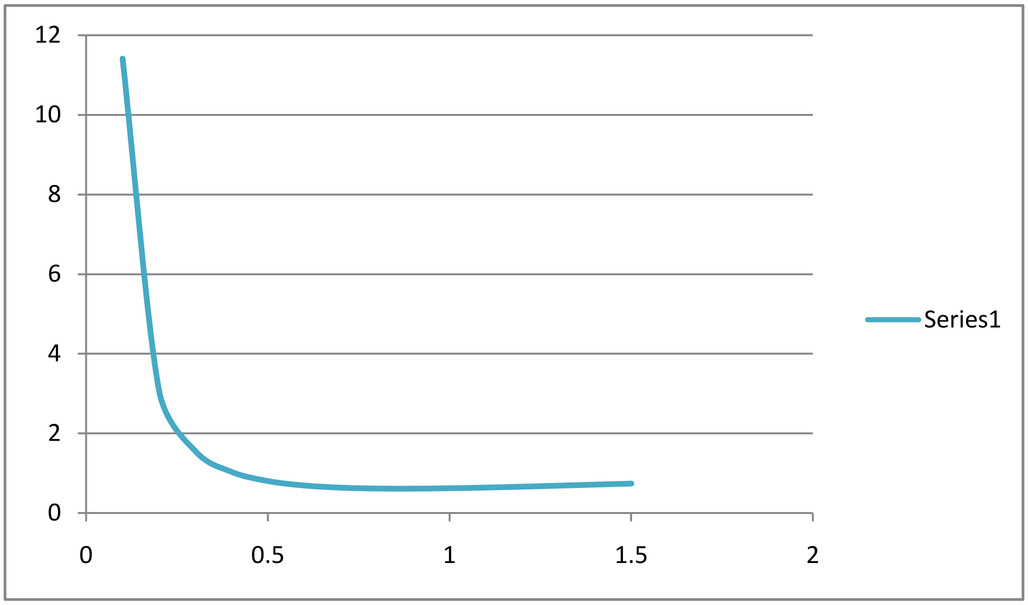


Fig 6.3 Phase noise plot for proposed third order oscillator Topology-III

It can be observed from graph that phase noise is high at frequencies less than the oscillation frequency and tend to decline as we move near to the oscillation frequency and reached down to Zero at oscillation frequency, Afterwards, it varies near to zero as we further increase the frequency. So, in this way we have learned phase noise variation with frequency for third order oscillators and learned that each oscillator has its unique response for phase noise. Next section evaluates these oscillators on the basis of THD.

6.2 Total Harmonic Distortion

In this section Total Harmonic Distortion is evaluated for different frequencies of oscillations and then graph is plotted between THD and Frequency of oscillation. Following sections contains the readings of THD with different frequencies of oscillations.

6.2.1 Second Order Sinusoidal Oscillators using Band Pass Filter

Frequency of oscillation is changed by varying values of resistances or capacitances involved and then THD is evaluated at each frequency using 0.5um AGILENT technology. These readings are tabled below:

Table 6.4 THD variation with oscillation frequency for proposed oscillator 1

S.NO	Frequency of oscillation (KHz)	THD (%)
1	49.625	0.5682
2	53.0516	0.467
3	53.7146	0.842
4	60.667	0.962
5	64.974	0.875
6	69.725	0.4704
7	75.06	0.977

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

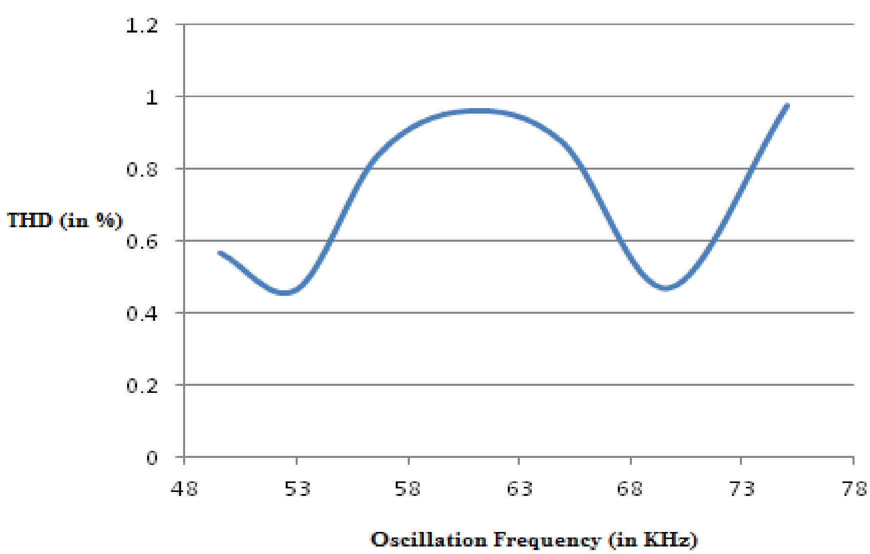


Fig 6.4 Graph of THD variation vs. oscillation frequency for proposed oscillator 1

After studying the graph, we observed that THD varies abruptly with frequency of oscillations as there are various slope changes in graph. But THD is found to be minimum at $\omega = 53.0516$ KHz.

6.2.2 OTRA based Hartley oscillator

Frequency of oscillation is changed by varying values of resistances or capacitances involved and then THD is evaluated at each frequency using 0.5um AGILENT technology. These readings are tabled below:

Table 6.5 THD variation with oscillation frequency for proposed circuit 2

S.NO	Frequency of oscillation (KHz)	THD (%)
1	339.319	1.709
2	348.134	1.403
3	357.674	1.591
4	368.043	1.989
5	379.37	2.213
6	391.812	2.101
7	405.564	2.393
8	420.874	2.414
9	438.059	2.070
10	457.54	3.140
11	479.87	2.02

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

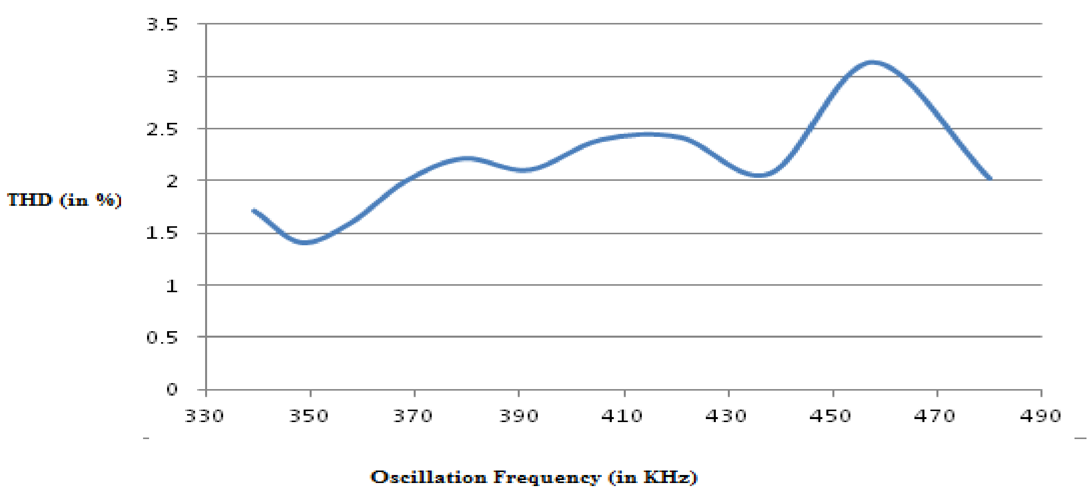


Fig 6.5 Graph of THD variation vs. oscillation frequency for proposed oscillator 2

After studying the graph, we got to know that THD varies abruptly with increase in frequency of oscillations as there are various slope changes in graph. But THD is found to be minimum at $\omega = 348.134$ KHz.

6.2.3 OTRA based Colpitts oscillator

Frequency of oscillation is changed by varying values of resistances or capacitances involved and then THD is evaluated at each frequency using 0.5um AGILENT technology. These readings are tabled below:

Table 6.6 THD variation with oscillation frequency for proposed oscillator 3

S.NO	Frequency of oscillation (KHz)	THD (%)
1	1438.564	12.14
2	1417.86	7.25
3	1398.033	7.15
4	1379.012	9.15
5	1360.746	5.31
6	1343.187	11.00
7	1326.291	12.468
8	1310.010	6.645
9	1294.327	7.609
11	1279.188	8.676

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

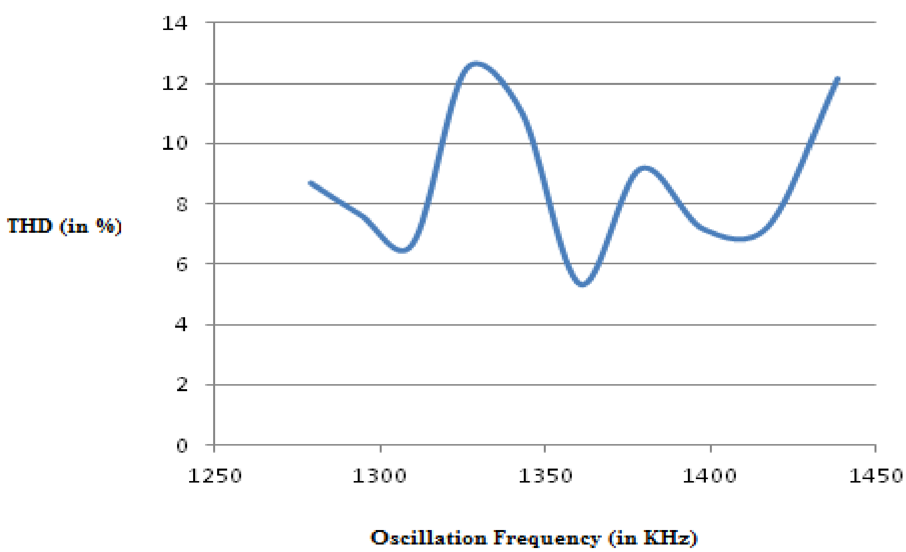


Fig 6.6 Graph of THD variation vs. oscillation frequency for proposed oscillator 3

After studying the graph, we got to know that THD varies abruptly with frequency of oscillations as there are various slope changes in graph. But THD is minimum at $\omega = 1360.746$ KHz .

6.2.4 Third Order Sinusoidal Oscillators-Topology I

Frequency of oscillation is changed by varying values of resistances involved and then THD is evaluated at each frequency using uA741 opamp in PSPICE for OP-AMP. These readings are tabled below:

Table 6.7 THD variation with oscillation frequency for propose third order oscillator-Topology I

S.NO	Frequency of oscillation (KHz)	THD (%)
1	7.189	5.823
2	6.255	2.972
3	5.212	2.030
4	4.488	1.938
5	3.909	1.448
6	3.475	1.217
7	3.127	1.531
8	2.843	1.143

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

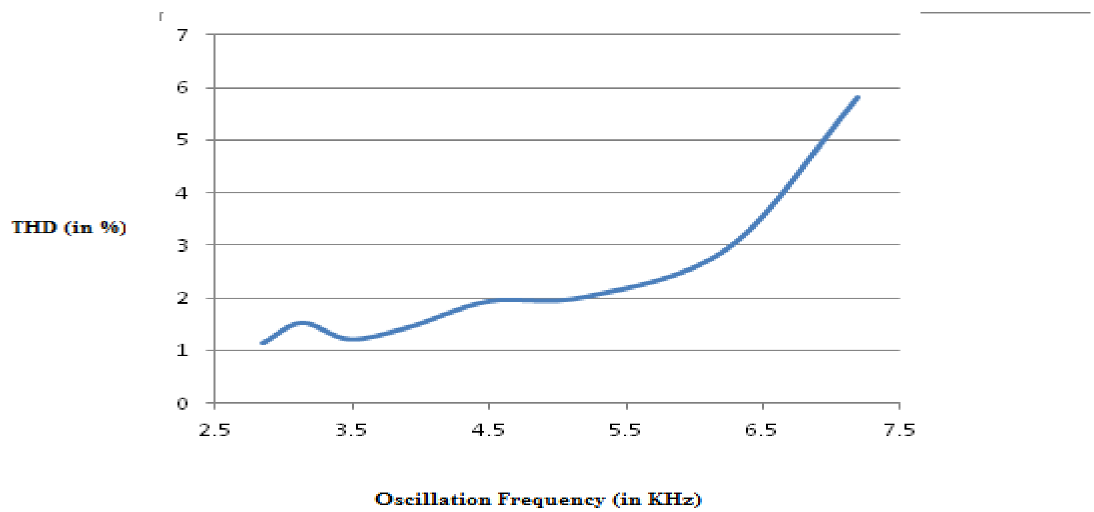


Fig 6.7 Graph of THD variation vs. oscillation frequency for proposed third order oscillator-topology I

It can be inferred from graph that THD is minimum at $\omega = 2.843$ KHz and tend to increase as we increase oscillation frequency.

6.2.5 Third Order Sinusoidal Oscillators-Topology II

Frequency of oscillation is changed by varying values of resistances involved and then THD is evaluated at each frequency using uA741 opamp in PSPICE for OP-AMP. These readings are tabled below:

Table 6.8THD variation with oscillation frequency for

Proposed third order oscillator-Topology II

S.NO	Frequency of oscillation (KHz)	THD (%)
1	1.244	1.155
2	1.327	1.146
3	1.421	1.223
4	1.537	1.764
5	1.658	1.770
6	1.809	1.438
7	1.990	1.790

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

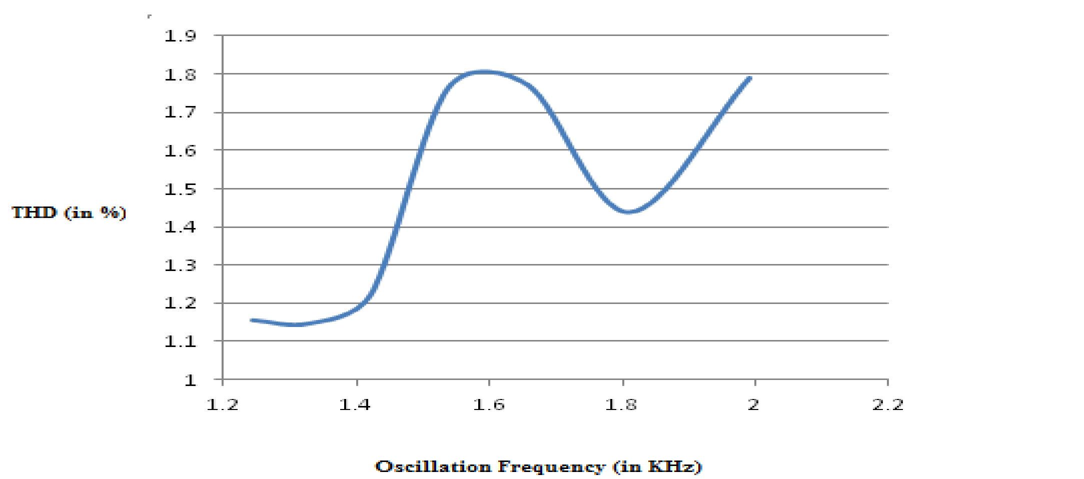


Fig 6.8 Graph of THD variation vs. oscillation frequency

for proposed third order oscillator-Topology II

After studying the graph, we got to know that THD is minimum at $\omega = 1.327$ KHz and tend to increase as we increase oscillation frequency up to 1.6 KHz and after that it declines till $\omega = 1.81$ KHz .Further increasing the oscillation frequency shows rise in THD again.

6.2.6 Third Order Sinusoidal Oscillators-Topology III

Frequency of oscillation is changed by varying values of resistances or capacitances involved and then THD is evaluated at each frequency using uA741 opamp in PSPICE for OP-AMP. These readings are tabled below:

Table 6.9 THD variation with oscillation frequency

For proposed third order oscillator-Topology III

S.NO	Frequency of oscillation (KHz)	THD (%)
1	2.8419	1.293
2	3.126	1.104
3	3.473	1.2
4	3.907	1.890
5	4.466	1.378
6	5.210	2.862
7	6.252	2.739

Then the results are plotted with THD on Y-Axis and Oscillation frequency on X-Axis.

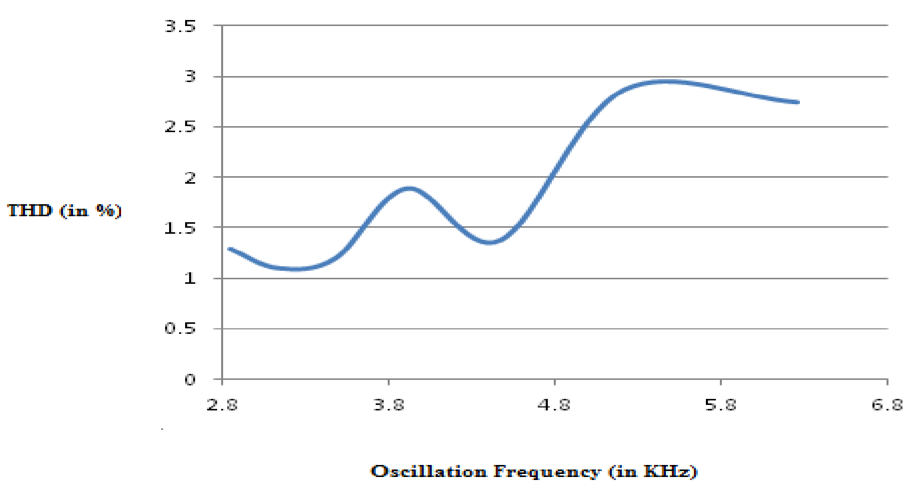


Fig 6.9 Graph of THD variation vs. oscillation frequency

For proposed third order oscillator-Topology III

After studying the graph, we got to know that THD varies abruptly with frequency of oscillations as there are various slope changes in graph. But THD is minimum at $\omega = 3.126$ KHz.

6.3 Frequency offset

It is known as deviation from the nominal output frequency i.e.

$$S = \frac{Fmeasured \ - Fnorminal}{Fnorminal} \quad (6.15)$$

Frequency offset is calculated for the proposed oscillators using equation (6.15) and tabled below:

Table 6.10 Frequency offset for proposed oscillators

S.NO.	NAME OF OSCILLATOR	$F_{norminal}$ (KHz)	$F_{measured}$ (KHz)	S
1.	Second Order Sinusoidal Oscillators using Band Pass Filter	318.31	316.92	-0.0044
2.	OTRA based Hartley Oscillator	339.26	337.94	-0.00389
3.	OTRA based Colpitts oscillator	1279	1235.7	-0.338
4.	Third order sinusoidal oscillator-Topology I	6.43	6.47	0.0031
5.	Third order sinusoidal oscillator-Topology II	1.989	1.973	-0.008
6.	Third order sinusoidal oscillator-Topology III	275.66	273.54	-0.007

It is observed to have positive frequency offset as well as negative frequency offset. And ,value of these frequency offset is found to be less than one for all oscillators, signifying that simulated oscillators produced oscillation frequency close to desired theoretical value.

6.4 Performance Comparison of Proposed Oscillators

This section summarise the results evaluated in previous section in tabular form shown in table 6.11 where $F_{min.THD}$ denotes the frequency of oscillation at which THD is minimum. The table gives the number of active and passive components used in the circuits along with the glimpse of results evaluated in previous sections of this chapter.

Table 6.11 Summary of evaluated Performance parameters

S.NO	Name of Oscillator	Number of Active Block used	Number of Passive components used	$F_{min.THD}$ (KHz)	Frequency Offset
1.	Second Order Sinusoidal Oscillators using Band Pass filter	1 OTRA	2 Resistors 2 Capacitors	53.0516	-0.0044
2.	OTRA based Hartley oscillator	1 OTRA	2 Resistors 1 Capacitor 2 Inductors	348.134	-0.0038
3.	OTRA based colpitts oscillator	1 OTRA	2 Resistors 2 Capacitor 1 Inductor	1360.746	-0.338
4.	Third order sinusoidal oscillator-Topology I	3 OP-AMP	8 Resistors 3 Capacitors	2.843	0.0031
5.	Third order sinusoidal oscillator-Topology II	3 OP-AMP	5 Resistors 3 Capacitors	1.327	-0.018
6.	Third order sinusoidal oscillator-Topology III	4 OTRA	8 Resistors 3 Capacitors	3.126	-0.007

From above table it can be concluded that designed second order oscillators give minimum THD in frequency range 50 KHz-1500 KHz i.e., at low frequencies whereas third order oscillators gives minimum THD in frequency range 1 KHz-10 KHz relatively less than second order. While frequency offset is very less for all five designed oscillators, third order oscillators are much more accurate than second order as their frequency offset is relatively less. As far as number of active and passive components is concerned, third order oscillators required them in greater number as compared to second order oscillators. Hence, it can be inferred that more accuracy comes with the price of more number of components which in turn increases circuit chip area.

So, in this way the performance parameters were evaluated for the proposed oscillators. The next chapter provides a conclusion of this thesis and also discuss about the future perspectives.

Chapter-7

CONCLUSION AND FUTURE PERSPECTIVE

In previous chapter designed second as well as third order oscillators were proposed and analyzed using three different parameters namely, phase noise analysis, THD variation with frequency and Frequency offset. This chapter draws a conclusion of the work done and also discuss the future perspectives.

7.1 Conclusion

This thesis focuses on design of second and third order linear oscillators and in depth analysis of performance parameters of these oscillators. Oscillators were designed using two active blocks namely OP-AMP and OTRA. The structures of Low pass and Band pass filters were studied and used in designing of the oscillators. The performance parameters of designed oscillators were evaluated on the basis of different parameters.

Second order oscillators were designed using band pass filters and tuned circuits. The second order band pass filter (designed using OTRA) was used as core block in designing of one of the second order oscillator .Then, the famous tuned circuits, Hartley and Colpitts oscillators were designed using OTRA. Sallen key low pass filter (for oscillators) was studied and then used as core structure along with lossy and loss-less integrators in designing the third order oscillator .One of the designed third order oscillator produced quadrature output. Then, the first order low pass filter using OTRA was analysed and then used in designing of third order oscillator. The proposed oscillators were simulated and their transient and frequency response were studied.

Also, Performance parameters of oscillators namely the phase noise, total harmonic distortion, frequency stability and effects of power supply variations were studied. The phase noise analysis provides mathematical formulae for oscillators employing third-order equivalent low pass filters in their feedback loop. These mathematical models are then used to compute phase noise sidebands for the proposed third order oscillators. THD for the oscillators was computed. Then, variation of THD with oscillation frequency was plotted for all proposed oscillators. Frequency offset was calculated for the proposed oscillators showing that the designed circuits were oscillating at frequency very near to desired frequency. Then, the proposed oscillators were compared on the basis of number of active and passive components used in their circuits.

7.2 Future Perspectives

While this work attempted to analyze performance parameters of oscillators, there were several parameters which still needed to be explored. Parameters like study of Allan variance for frequency instability can also be calculated for these oscillators. Along with this other parameters like warm up time, power dissipation can be studied to make these designs more practical and market oriented. Efforts can be raised to reduce the active and passive components in the circuits of the proposed oscillators. In this work, third order oscillator design using three first order low pass filters and inverting gain stage is presented which uses four OTRA active blocks. This circuit can be further explored to reduce number of OTRA into three by incorporating gain stage into one of the three OTRAs used for first order low pass filter.

Reduction of chip area is an important aspect in integrated circuits. Hence, it could be useful to implement the resistors using transistors, which would reduce the size considerably. The current differencing property of the OTRA makes it possible to implement the resistors connected to the input terminals of OTRA, using MOS transistors with complete non linearity cancellation [1]. The resulting circuit will consisting of only MOS transistors and capacitors are called MOS-C realization. This will save a significant amount of chip area and lead to circuits that are electronically tuneable. That is, the resistance values and hence the related oscillator parameters can be adjusted by simply changing the gate bias voltages.