

INTRODUCTION

1.1 INTRODUCTION TO CURRENT-MODE CIRCUITS

Sinusoidal/square waveform generators are the basic building cells in many electronic circuit systems. For example, in instrumentation, measurement systems, communication systems, power conversion control circuits and signal processing application [1]. The sinusoidal and square waveform generators along with other circuits are often employed to produce various standard signals, such as triangular wave, pulse wave, etc. Since the introduction of integrated circuits, the operational amplifier (op-amp) has been serving as the basic building block in many electronics circuit designs. Since then, new integrated analogue circuit applications have emerged and the performance requirements for analogue circuits have changed. A typical voltage-mode waveform generator can be implemented by using an op-amp with a few passive components. Verities of waveform generators using voltage mode op-amp are available in the literature [2, 3]. These voltage-mode (op-amp) circuits yield some drawbacks such as complex internal circuitries, lower slew rate, constant gain bandwidth product and more passive components are however required to generate the waveforms. The finite gain bandwidth product of an op-amp affects the performance of the waveform generator. Furthermore, the limited slew rate of the op-amp affects the large signal and high frequency operations [4-6]. Analogue circuit design has historically been dominated by voltage-mode signal processing. In voltage-mode, current signals are transferred into a voltage domain before any analogue signal processing. This makes an integrated circuit (IC) unsuitable for low voltage application. When low voltage, low power consumption and wide bandwidth are required simultaneously, the voltage-mode devices easily become too complex and failed to achieve the required characteristics [7]. The performance of a circuit in analogue circuits is determined in terms of voltage levels at the different nodes in the circuit including input and output nodes are known as voltage mode circuits. Large output voltage swing while minimizing the total power consumption is required to provide in voltage mode circuits. This causes high impedance node architecture in the voltage mode circuits. In voltage mode circuits with large voltage swing, the parasitic

capacitances presented in the circuits need to be charged and discharged, this leads to decrease of the speed and slew rate in the voltage mode circuits.

Apart from the op-amps or voltage-mode approaches, another circuit design concept, current-mode technique was introduced [4-7]. The current mode circuits are low impedance circuits. The performance of the current mode circuits in terms of speed and slew rate is very high compared to the voltage mode circuits. By using the current signals instead of voltage signals, the current mode circuits are able to operate with low supply voltages. The addition operation in current mode circuit is much easier than the voltage mode circuits. By using KCL (Kirchhoff's Current Law), the addition and subtraction is possible by joining the terminals at a node in the current mode circuit. This eliminates the passive components, reduces the power consumption and chip area compared to the voltage mode. In addition to the above stated advantages, the dynamic range of the current mode circuits is larger than that of the voltage mode circuits. The first current-mode based active device named current conveyor (CC) was introduced in 1968 [6]. Since then, many new active current-mode devices have been reported in the literature [8-17]. Second and third generation current conveyors were introduced in 1970 and 1995 [6]. The terminal relations for the first, second and third generation current conveyors are different. Based on the output terminal current direction, the current conveyors are further classified as CCII+ and CCII-. The Operational Transconductance Amplifier (OTA) is used to drive the capacitive loads [8]. Many applications are available in the literature using Current Feed-back Operational Amplifier (CFOA) [9]. CFOA has the similar terminal relation with respect to the CCII. Few current mode devices are listed below.

- i) Four Terminal Floating Nuller (FTFN)
- ii) Current Differencing Buffered Amplifier (CDBA)
- iii) Current Controlled CDBA (CC-CDBA)
- iv) Current Differencing Transconductance Amplifier (CDTA)
- v) Current Controlled CDTA (CCCDTA)
- vi) Voltage Differencing Transconductance Amplifier (VDTA)
- vii) Voltage Differencing Buffered Amplifier (VDBA)

In previous researches, some waveform generators were presented based on current-mode devices [18-30]. These current-mode waveform generators have attracted much attention of the analogue integrated circuit designers due to the

advantages over voltage mode waveform generators such as; the oscillation frequency can be adjusted more accurately, the oscillation frequency is less sensitive to the bandwidth variation of the active devices and because of the large slew rate, the current-mode oscillator can achieve higher frequencies at larger amplitude levels.

1.2 MOTIVATION OF THE WORK

The modern integrated circuit technologies are normally developed to be driven by the needs of digital CMOS circuit design. As the size of integrated devices decreases, so maximum voltage ratings are also rapidly reduces. Although decreased supply voltages do not restrict the design of digital circuits, it is harder to design high performance analogue integrated circuits using new processes. In digital integration technologies, there are fewer integrated devices available for the circuit design. In the worst case situation, this means that only transistors are available for analogue circuit design. There may occasionally be capacitances and resistors, but their values may be small and there are significant parasitic components present. Thus, if we want to utilize the fastest integration technologies available, which are normally restricted to the active components in the design of integrated analogue circuits. Since the introduction of integrated circuits, the operational amplifier has served as the basic building block in analogue circuit design. When signals are widely distributed as voltages, the parasitic capacitances are charged and discharged with the full voltage swing, which limits the speed and increases the power consumption of voltage-mode circuits.

One procedure for finding alternative, preferably simpler, current-mode approach is preferred rather than the traditional voltage-mode structures for signal processing [4-7]. Current-mode circuits cannot avoid nodes with high voltage swing either, but these are usually local nodes with less parasitic capacitances. Therefore, it is possible to reach higher speed and lower dynamic power consumption with current-mode circuit techniques. Since the concept of the current conveyor was brought into being, there are many current-mode analogue building blocks developed and the related applications have been reported in the literature [8-30].

In the past few years, an active device called Operational Transresistance Amplifier (OTRA) is reported and applied [31-38]. Several OTRA-based implementations have emerged. OTRA, being a current processing analogue building

block, inherits all the advantages of the current mode technique and therefore is ideally suited for high frequency applications [39-43]. It is also free from parasitic input capacitances and resistances as its input terminals are virtually grounded and hence, non-ideality problem is less in circuits implemented with OTRA. Low input, output impedances and device gain which is bandwidth independent are the main advantageous properties of the OTRA. The OTRA has also been using as one of the basic building blocks in the field of analogue signal processing [44-60]. OTRA is designed for low voltage operation, low power consumption, wide bandwidth, high speed, greater linearity and simpler circuit complexity. Several circuits for different applications have been reported in the literature [61-88] based on OTRA as a main active element, such as instrumentation amplifiers, MOSFET-C differentiator, integrators, continuous-time filters, immittance simulators, waveform generators, bistable multivibrators and oscillators.

1.3 OBJECTIVES

In the last decade, few number of current-mode sinusoidal/square waveform generators were introduced in the area of analogue signal processing. However, the researchers still aim to design and develop new waveform generator circuits to improve the characteristics of the existing circuits to achieve better features than their counterparts. These better features can be described as less number of passive components, and less number of active components, high frequency performance/inherent signal bandwidths, greater linearity, lower power consumption, lower supply voltages and simplicity in circuit designing. Sinusoidal/square waveform generators are widely used in analogue signal processing. Few sinusoidal/square waveform circuit realizations using different active building blocks have been reported in the literature. These circuit realizations have some drawbacks such as more active/passive components.

Therefore, the main aim of this thesis is to design, develop and testing of new sinusoidal/square waveform generators. The first intention is to design a generalized configuration for the sinusoidal oscillator with one active component, minimum number of passive components and a grounded resistor/capacitor. By using this generalized configuration a few number of oscillator circuits can be realized. The oscillator circuits, which are realized from the generalized configuration, are

controlled by the single grounded resistance/capacitance. Quadrature oscillator is an important building block in many communication, control systems, instrumentation and measurement systems. Therefore, part of this work is attempted on this issue.

The square-wave generator is widely operated in many electronic fields such as digital, instrumentation and communication systems. Conventional square waveform generator circuits pose some drawbacks such as complex internal circuitries, lower slew rate, constant gain bandwidth product, more passive components and non-linear variation of the time period with respect to the passive components. Hence, the intension is to design a square-wave generator with minimum number of passive components, one active component and improved linearity with respect to the passive components connected to the circuit.

In the first step the theoretical analysis is done. To verify the behaviour of the proposed circuits, OTRA is implemented with CMOS transistors and checked for waveform generation. The feasibility of the proposed circuits is also confirmed by the experimental measurements.

1.4 ORGANIZATION OF THESIS

Chapter (2) deals with an introductory overview of the operational transresistance amplifier (OTRA) and its CMOS implementation. Three CMOS OTRA implementations are discussed in this chapter. These CMOS OTRA implementations are already reported in [32-35]. Two of these CMOS OTRA implementations are based on the modified differential current conveyor (MDCC) and a common source amplifier. The OTRA implemented with differential current controlled current source (DCCCS) followed by a buffer [35] is discussed. The operation of these three OTRAs is studied and simulated using Cadence gpdk 180 nm CMOS model parameters.

Chapter (3) provides the background review of the existed waveform generators by using OTRA. Two square waveform generators, one square/triangle waveform generator and some sinusoidal oscillator circuits existed in the literature [46-58] are discussed in this chapter. These circuits are designed and simulated using Cadence Spectre simulation model parameters. The advantages of these circuits are quoted and their drawbacks have been detected during the implementation and simulation is given in this chapter.

Chapter (4) introduces some new waveform generator circuits. In this chapter, a generalized configuration for sinusoidal oscillator circuits, two quadrature sinusoidal oscillators and two square waveform generator using OTRA are proposed. The generalized configuration proposed in this chapter is used to produce few sinusoidal oscillator circuits. The operations of the proposed circuits to produce oscillations are discussed in detail. The quadrature sinusoidal oscillators and square waveform generators operations are discussed in this chapter.

Chapter (5) describes the mathematical analysis of the proposed circuits in chapter 4. The basic network laws and ideal terminal characteristics of OTRA are applied to the proposed circuits to derive the oscillation frequency and condition of oscillations for the oscillator circuits realized from the generalized configuration. Similarly, the same procedure is applied to derive the mathematical equations for the quadrature sinusoidal oscillators and square waveform generators.

Chapter (6) deals with the non-ideal analysis of the proposed circuits. The transresistance gain of the OTRA is infinite in an ideal case. But, practically, the OTRA transresistance gain is finite and its effect should be considered. In this chapter, all the proposed circuits in chapter (4) are reanalyzed based on non-ideal characteristics of OTRA.

Chapter (7) deals with the simulation results of the proposed circuits in chapter (4). All the proposed circuits are checked for waveform generation by connecting with passive components. The passive component values are calculated from the mathematical equations derived in chapter (5). All the proposed circuits are simulated using Cadence Spectre simulation model parameters. Further the simulation results are presented in this chapter to validate the mathematical analysis carried out in chapter (5).

Chapter (8) presents hardware implementation of the proposed circuits on a laboratory bread board. The OTRA prototype circuit is implemented by using two AD844 AN ICs and external passive components are connected to test the waveform generation of the proposed circuits. The proposed circuits are tuned for different passive component values. Hardware results are given in this chapter to validate the simulation and theoretical analysis.

Chapter (9) presents the advantages of the proposed circuits compared to the existing circuits in the literature based on OTRA. In the end, conclusions and future scope are given in this chapter.