Realization of VDCC based PI, PD and PID Controller

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IN
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CANDIDATE'S DECLARATION

I, TAMANNA SINHA, Roll No 2K18/VLS/16 student of M.Tech (VLSI DESIGN AND EMBEDDED SYSTEM), hereby declare that the project titled **"Realization of VDCC based PI, PD and PID Controller"** which is submitted by me to the Department of ELECTRONICS AND COMMUNICATION ENGINEERING, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project titled **“Realization of VDCC based PI, PD and PID Controller”** which is submitted by TAMANNA SINHA, Roll No 2K18/VLS/16, Electronics and Communication Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part of full for any Degree or Diploma to this University or elsewhere.

Place: Delhi	**DR. DEVA NAND**
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ABSTRACT

The presented work deals with Voltage differencing current conveyor (VDCC) and its use in analog circuit design. Several major developments have been take place in the area of analog circuits over the last few decades. Ever since the introduction of current conveyor as basic building blocks in analog circuit designs, there is a bulk of material available about various current mode analog building blocks developed past current conveyor.

For circuit design, Voltage Differencing Current Conveyor has emerged as quite versatile and flexible analog building block among diverse modern active building blocks. The Voltage Differencing Current Conveyor (VDCC) having the features of two very basic and important analog building blocks, a current conveyor of second generation (CCII) and an operational transconductance amplifier (OTA). This current mode VDCC has higher usable gain, higher frequency range of operation, small power consumption, higher slew rates, improved linearity, and better accuracy. Current mode approach is not only limited to current processing but also offers important advantages when interfacing with a voltage mode type circuit. The Voltage differencing current conveyor (VDCC) is an active building block that provides electronic tunability of transconductance gain in addition to that it also transfers both current and voltage in its related terminals, perfectly for the designing of various active filters, inductor, simulators and controllers.

In this project an attempt has been made to highlight the realization of VDCC active building and its application as PID controller. . Initially AC and DC characteristic of VDCC has been studied and then PID Controller output is realized. In the proposed circuit, the bias current variation is used for electronic tunability of the proportional gain constant, integral time constant and Derivative time constant. Grounded passive elements such as Resistors and Capacitors are used which makes it perfectly suitable for on-chip implementation. The validity of the circuit is verified by PSPICE simulations using 0.18μm TSMC CMOS technology parameters.

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CHAPTER 1

INTRODUCTION

1.1 Background

With scaling technology and increasing demand of compact and portable electronics devices, researchers are working towards the development of mixed mode signal processing circuits with low-voltage and high performance. Because analog circuits are simultaneously integrated with digital circuits on the same chip, and analog circuits must be designed to work at lower supply voltages. In last few decades several novel active building blocks (ABBs) have been introduced in the realm of analog signal processing. Most of these ABBs are used to generate current from a differential voltage input through a transconductor. Throughout the present work an attempt has been made to highlight some basic building blocks of analog circuit design and the developments leading to the implementation of voltage differencing current conveyor block (VDCC) and application of this block as PID controller.

The traditional operational amplifier (op-amp) [1] is a highly versatile element which was introduced in the early 1940s. Op-amps are used for the realization of many circuits both linear and non-linear. Extensive research had been carried out from mid sixties and mid-eighties on the design of various linear and non-linear analog circuits using op-amp IC (Integrated circuit). The op-amp based circuits usually employ RC elements and since the precise tuning of the time constant RC is difficult to implement hence their monolithic IC implementation is difficult. The efficiency of these circuits is reduced due to smaller bandwidth, slew rate etc. This forced the analog designers to look for other alternate active building blocks [2]. Switched capacitor circuits was one of the solutions where the resistor was replaced by a periodically switched capacitor but it again posed problems like aliasing and clock feed through [3].

In eighties the Operational Transconductance Amplifier (OTA) was introduced. This OTA-C circuit only employs transconductors and capacitors to build different usable circuits and therefore does not need any resistors. Moreover, the OTA-C's internal structure does not consist of any resistor which adds advantage to the list. The OTA circuits are programmable i.e. transconductance being controlled electronically through an external DC bias current and voltage. Past one decade has seen developments in digital circuit design, particularly CMOS digital circuits, which has had a deep influence on the developments in analog circuits as well, more precisely the mixed-mode circuit design which consist of both analog and digital circuits [2] integrated using the same technology on the same chip. Although the digital circuits and systems have many advantages over the analog type, the still latter cannot be avoided as the natural world is analog. The analog designers faced various challenges of matching the analog circuits and systems with their fast-growing digital counterparts, due to the various developments in the field of integrated circuit (IC) technology. These requirements led to continued research to develop efficient analog circuit designs especially current-mode (CM) techniques and circuits as the solutions for the problems posed by the mixed-mode circuit design that is prevalent these days. The current mode approach to signal processing and circuit design has its advantages such as higher operating frequency, lower power consumption, higher slew rates, better linearity and improved accuracy, but still the approach to voltage mode is also equally important because it offers simpler solutions to given problems.

1.2 Analog and Digital signal processing

First we will analyze some of the basics of signal processing before describing the developments in analog signal processing and circuit designs and find application in various fields of engineering which include communication and control systems, instrumentation and measurement system, bio-medical, etc. The two different ways to implement signal processing are given as:

(1) Analog or continuous time method and
(2) Digital or discrete time method.

As long as solutions were based on the Fact that the real world is analog, the analog signal processing was dominant. It uses some parts of analog type circuit constituents such as diodes, transistors, resistors, capacitors etc. With the emergence of digital computer and microprocessor, the digital signal processing started edging its analog counterpart and has become dominant now a days. To solve equation of differential type that describes a physical system, analog signal processing is easy as it has the natural ability of the system; the solutions thus obtained are in real time. On the other hand, for numeric calculations we rely on digital signal processing. But this method may sometimes not give accurate results in real time. The digital signal processing has few advantages over analog signal processing approach; the two prominent among them are-

(1) Repeatability: In analog systems if there is some change in parameter such as change in temperature or change in supply voltage, the results may varied while in digital type of signal processing we get same result over and over again for the same repeated operation. Apart from these, signal processing of digital type has many other advantages over signal processing of analog type such as better noise immunity, compact in size and much cheaper than their analog counterpart. The digital system also gives the facility to encrypt the signal and transmitted over channel and only the intended receiver can decode it. It also enables multi directional transmission over a long distance simultaneously. Because of many advantages of digital system, the designers try to look for digital solutions rather than analog for the problems of VLSI system design. Even though there are many advantages of digital system, the analog circuits and systems are still fundamentally necessary in many complex and high-performance systems because in reality, all signals in the physical world are continuous in both time and amplitude. Hence for conditioning of such analog signals, before they can be processed by digital signal processing circuits, analog techniques will always be required. Another important reason for the existence of analog signal processing is the bandwidth which is of higher range, if the signal is processed in analog circuits than in digital circuits.

(2) Flexibility: Similar forms of digital signal processing operation may be performed using same hardware; while in analog signal processing separate hardware needs to be built for each form of operation.

1.3 Current Mode and Voltage mode signal processing

The signal processing which is done on electric or electronic circuit performed by means of organized movement of charges, where currents and voltages are usually the variables of time, capacitances, inductances and resistances are parameters of the circuit defining the properties of the signal processing. The reason behind using only voltages and currents in analog signal processing is that the active devices, which are used in analog electronics, operate mostly with resistances (conductance), as parameters for controlling the signal processing. The signal is then processed by miscellaneous current-voltage and voltage-current conversions, amplification, weighted addition and multiplication, etc. [4]. In the past, processing in terms of voltages is easier and simpler for the designers than in terms of currents, voltage had been used as the main variable for signal processing. Only voltage mode processing was practical during the initial years of analog electronics and the building blocks used in analog electronics (like op-amp) were typically voltage processing circuits.

As the time passed, challenge had aroused in front of designer to increase speed of analog circuit processing and decrease of supply voltage thus they started devoting more attention to the so-called current mode. In the current- mode the individual circuit elements were meant to interact by the means of current and not by the voltage which is the main advantage of current mode circuit. The difference between voltage and current processing circuits is that a single output terminal of a current processing block is able to supply only a single input terminal, since the inputs of the current processing blocks can’t be arranged into a serial connection. Therefore, if more input terminals are required to be supplied by the same input signal, it is necessary to design current processing building blocks with multiple outputs giving the same output signal while in voltage processing circuits a single voltage-output terminal can supply more voltage- input terminals connected in parallel.

As more and more advances in the field of analog system and circuits were made, need for some application specific modes also aroused. In certain circuits, the input was current and the output was needed to be voltage, these circuits were called trans-impedance mode circuits. Similarly, in some other circuits the input was voltage and the output was needed as current, such circuits are called trans-admittance mode circuits. These modes are however very application specific.

1.4 Analog Circuit Design

Principally, Digital circuits can operate only with two voltage values, while analog circuits can process the signals with continuous variation of voltages. But we k0now the fact that no macroscopic signal can truly quantized, so the digital circuit designers must have some familiarity or knowledge of analog electronics also to work with signals. Therefore analog circuit design thus plays a very significant part in the modern day of integrated circuit technology. The basic and most common used analog electronic circuits are: filters, active filters, oscillators, active oscillators, multi-vibrators, rectifiers, mixers, etc. A simple analog filters or passive filters consist of either all three or any two out of resistors, capacitors and inductors. And accordingly we have, RC, RL, LC and RLC circuits. Using these passive circuits a filter can be designed by blocking certain frequencies and passing other signal frequency.

The active filters are those filters which uses active components like amplifiers in their circuit along with some passive elements. Inclusion of active components, like amplifiers, it improves the performance and expectedness of a filter, while the requirement for inductors is also avoided as inductors are typically expensive and bulky. An amplifier inhibits the load impedance of the succeeding stage from upsetting the characteristics of the filter. But on the other hand active devices also bring some limitations to the circuits like finite bandwidth, noise injection, and more power consumption into the circuit, etc.

Another type of active filter is a biquad filter, can also be called as bi-quadratic filter. This linear filter implements transfer function in the ratio of two quadratic equations thus called as bi-quadratic filter. These Biquad filters are active filters which are implemented using a single-amplifier biquad (SAB) or two integrator loop topology. The SAB i.e. single-amplifier biquad topology produces complex poles and probably complex zeros using feedback to produce proper filter properties and the feedback moves the RC circuit real poles. On the other hand, the two integrator loop topology deriving from rearrangement of a bi-quadratic transfer function is represented as the sum of another signal, its integral and the integral’s integral.

An electronic oscillator having signaled oscillating electronically yields a wave either sinusoidal or square. An oscillator converts DC from a power supply to an AC signal. To produce sinusoidal output linear oscillator is used. These oscillators comprise of an amplifier, a frequency selective element, and a filter. The most common type of linear oscillator is an oscillator with positive feedback. In this type of feedback oscillators, the frequency selective filter is generally of two types: RC and LC. In an RC feedback oscillator circuit, the filter is a comprised of two passive element resistors and capacitors. RC oscillators are used to generate low frequencies, the frequency lie in the range of audio. On the other hand, an LC oscillator circuit comprises of a tuned circuit, also called tank circuit, containing passive element inductor and capacitor connected together.

A multi-vibrator is an electronic circuit used to implement a various other two- state systems such as timers, flip-flops and oscillators. It comprises of two cross –coupled amplifying devices by capacitors and resistors. Basically, there are different types of circuits called multi-vibrator depending on the operation of the circuit: a-stable, mono-stable and bi-stable multi-vibrators. Multi-vibrators mainly find application in the systems where timed intervals or square waves or are required.

Rectifier circuits are those which convert AC supply into DC. However, simple diode circuits can also perform rectification but its efficiency is not very high that is why sometimes we use active rectifier circuits which are implemented by utilizing active analog blocks. Mixer circuits are also very important part of the communication systems especially the receiver's side of signal processing.

Similarly there are few other analog circuits that can be implemented by active elements or passive elements or combination of both active and passive elements [1].

1.5 Motivation

A Voltage differencing current conveyor (VDCC) is an active building block in current mode. Presently current mode technique has become more common than voltage mode due to its more potential benefits such as greater dynamic range, higher signal bandwidth, higher linearity and simpler circuitry and lower power consumption [1].

The active block and proposed PID Controller/ have the following advantages

(1) Makes output both inverted and non-inverted simultaneously from the same configuration.
(2) Grounded passive components are advantages for integrated monolithic technology.
(3) The proposed circuit does not require any matching of passive component.
(4) The parameters of the PID controller can be tuned electronically: independently and arbitrarily.

1.6 Objectives

The main purpose of this report is to understand the working of Voltage differencing Current Conveyor (VDCC). They provide electronically tunable transconductance Gain .Also by understanding the fundamental port characteristics of VDCC one can realize any circuit for further realization of filters and controller . Realization of PID Controller and its advantages when it is used in closed loop system.

1.7 Organization of Report

This report study has been organized into four chapters. Chapter 1 deals with the introduction of VDCC. It also includes the Background of analog circuit design, modes of signal processing, motivation and objectives of the report. Chapter 2 deals with literature review where previously design PID controller is explained. In chapter 3, VDCC block is explained in detail. Chapter 4 deals with Realization of PI , PD and PID Controller with the help of different controller block and its application in closed loop system is presented. Chapter 5 includes the simulation results of active block and Controllers. And Chapter 6 Conclude the report and future scope of the PID controller and VDCC block.

CHAPTER 2

LITERATURE REVIEW

In this chapter, description of various active building block used for the realization of the PID controller is presented. Though a lot of PID controller using active building blocks has been proposed by various researchers in recent years but here we described those active building blocks which are directly used for PID controller implementation.

2.1 Operational Transconductance Amplifier (OTA)

OTA i.e. Operational transconductance Amplifier integrated circuit was first produced by RCA in the year 1969 for the purpose of commercial needs. In 1985 the first publication with OTA came out with new CMOS based OTA architectures and new filter Realization.

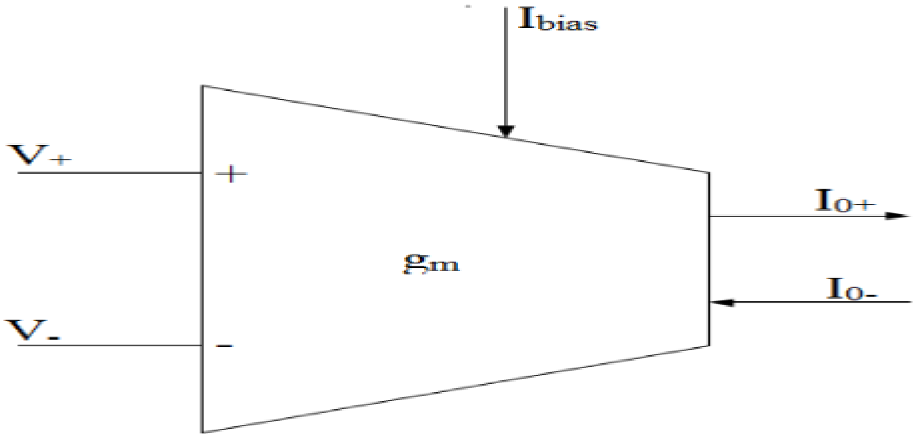

Fig.1 OTA Block Diagram [6]

OTA is a voltage controlled current source i.e. VCCS. In which by varying output voltage source output current can be controlled and it is characterized by transconductance i.e. g_m.

The OTA output current is given as

$$I_o = g_m (V_+ - V_-) \qquad (1)$$

Where $V_+$and V_- are the voltages on both the input terminal of OTA i.e. Non-inverting and Inverting.

Characteristics of an ideal OTA - Input Impedance = ∞, Output Impedance =∞, Bandwidth = ∞

The OTA (Operational Transconductance amplifier) is a voltage differential current controlled source. In this following we see CMOS implementation of differential input differential output OTA given in [6]. The trans-conductance is -

$$g_m = \sqrt{\mu_n C_{ox} \frac{W}{L} I_b} \qquad (2)$$

Where μ_n is the electron mobility of n-type MOSFET, C_{ox} is gate oxide capacitance per unit area, $\frac{W}{L}$ is transistor aspect ratio and I_b is bias current of OTA. In the above equation the trans-conductance g_m is adjustable by a supplied bias currentI_b.

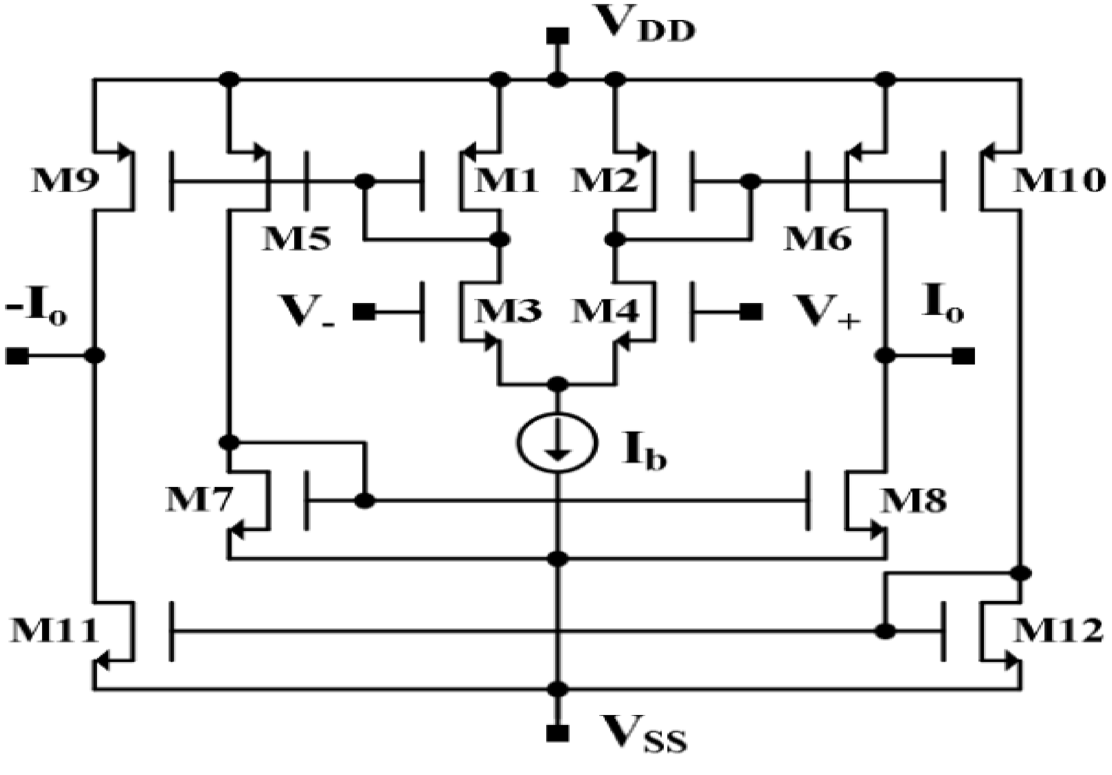

Fig.2 CMOS Realization of OTA [6]

2.1.1 OTA Based PID Controller

A PID controller realization using OTA is present in this section. Fig.3 shows PID controller where OTA 2 and 3 along with capacitor C_1 makes gyrator which simulates an Inductance with the value of $L = {}^{C_1}/_{g_{m_2} g_{m_3}}$. OTA 1 and this inductance configure the derivative circuit. OTA 4 with capacitor C_2 forms an integration circuit. OTAs 5 and 8 describe proportional gain [7].

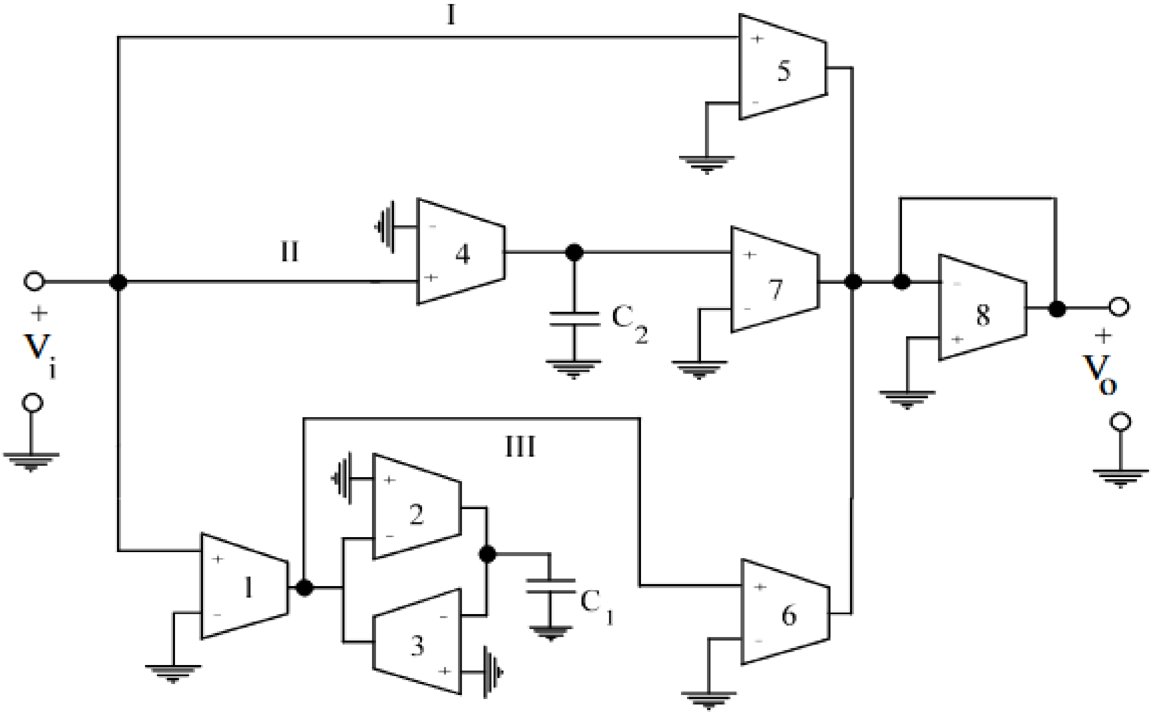

Fig.3 PID controller realization using OTA [7]

The controller gainK_P, K_I and K_D will be obtained as

$$K_P = \frac{g_{m_5}}{g_{m_8}} \tag{3}$$

$$K_I = \frac{g_{m_4} g_{m_7}}{C_2\, g_{m_8}} \tag{4}$$

$$K_D = \frac{g_{m_1} C_1 g_{m_6}}{g_{m_2} g_{m_3} g_{m_8}} \tag{5}$$

Thus the controller gain depends mostly on the ratios of transconductance of the OTAs. But the problem with this circuit is the number of OTAs required i.e. 8 and connections are complicated and gives output in only voltage mode.

2.2 Current Conveyor

The first- and second-Generation current conveyor was introduced by Sedra and Smith. The first generation was presented in the year 1968 [8] and further developed second generation current conveyor in the year 1970 [9] and third generation was proposed in the year 1995 [10].

2.2.1 First Generation Current Conveyor (CCI)

Current Conveyor (CCI) is characterized by a three port network has X , Y, and Z terminal as shown in below Fig.4 and its implementation using CMOS is shown in Fig.5.

Fig.4 CCI Block Diagram [8]

CCI employs both voltage and current in X and Y ports which are equal and a replica of current is conveyed to the output terminal Z . CCI can expressed in matrix form as follows [12]

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

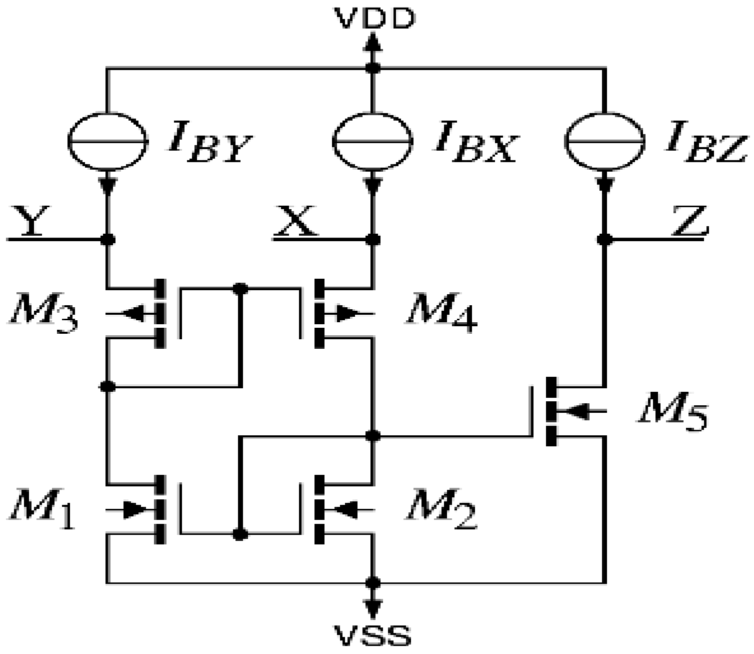

Fig.5 CMOS Realization of CCI [8]

2.2.2 Second Generation Current Conveyor (CCII)

CCII is a second-generation current conveyor which is a voltage follower with Y as input voltage terminal and X is a terminal which gives an output voltage and a current follower with a current input X and a current output Z connected together. It has a high input impedance and no current is flowing in terminal Y. It is used in many applications by increasing the versatility of current conveyor CCI [11].

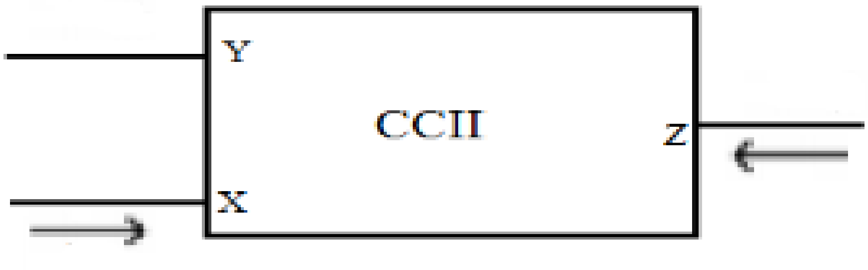

Fig.6 CCII Block Diagram [11]

CCII matrix form is as follows [11]

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

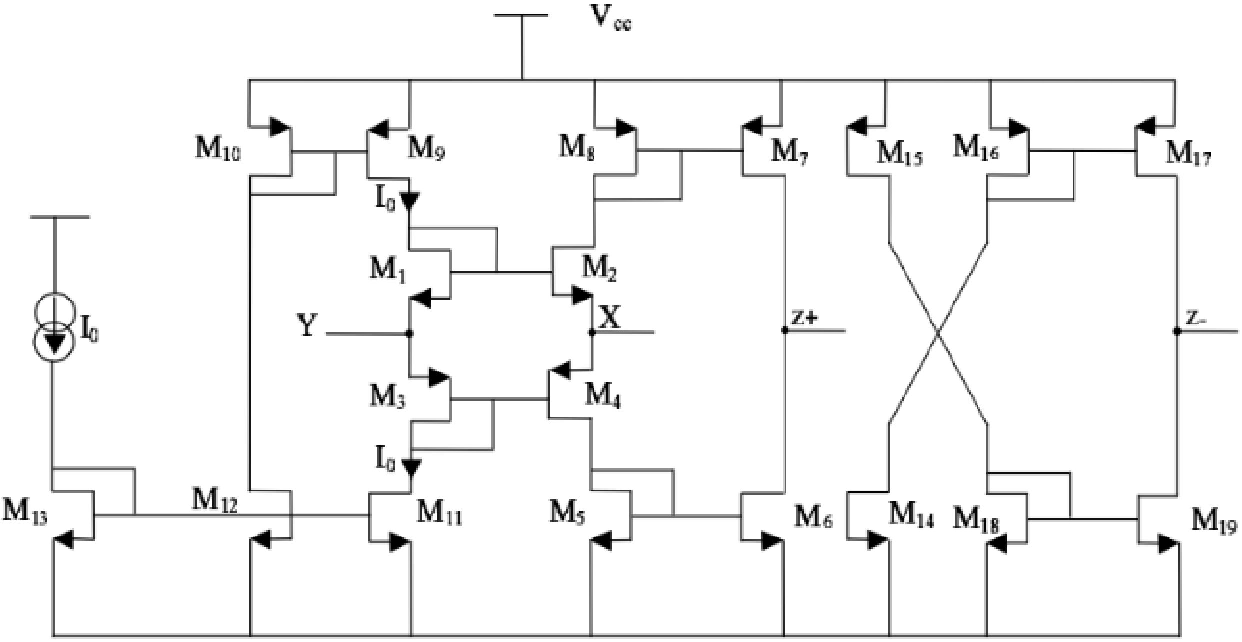

Fig.7 CMOS Realization of CCII [13]

2.2.3 Third Generation Current Conveyor (CCIII)

This third-generation Current conveyor (CCIII) is similar to first generation CCI except there is a transfer of current in opposite direction in X and Y terminal. The block diagram of CCIII and its realization using CMOS is shown in Fig 8 and Fig.9.

Fig.8 CCIII Block Diagram [12]

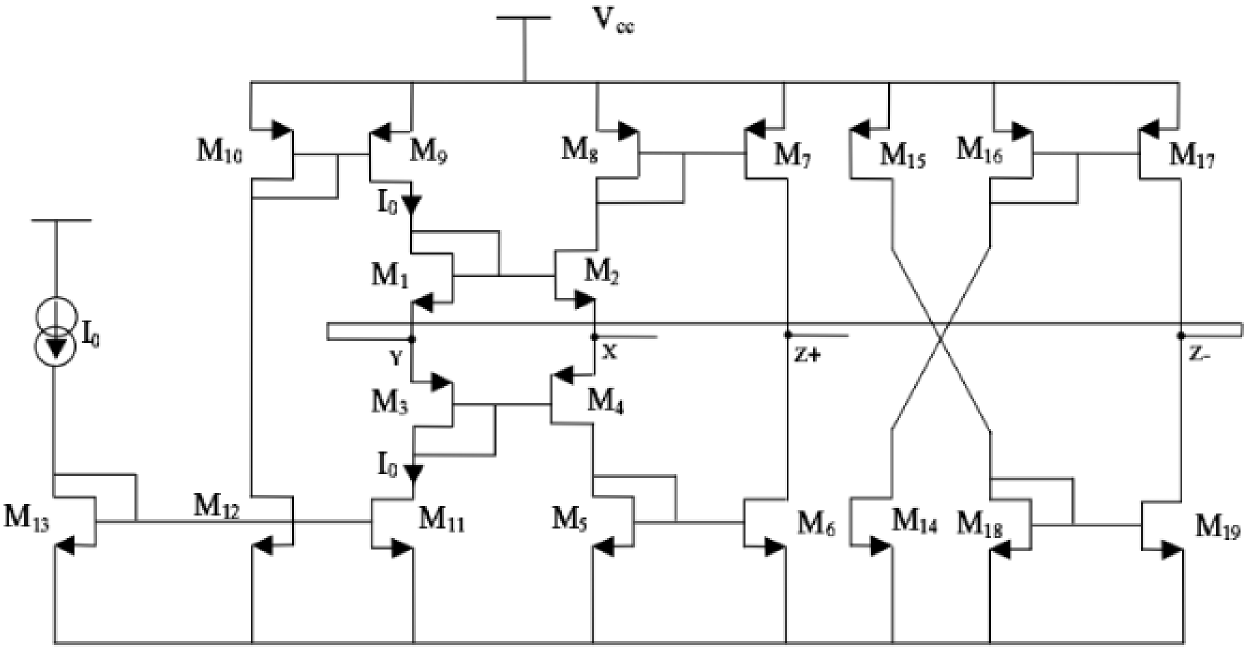

Fig.9 CMOS Realization of CCIII [12]

CCIII matrix form is as follows

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

2.2.4 CCII Based PID Controller

Voltage-mode and Current mode PID controllers employing the second-generation current conveyors (CCIIs) as active elements are described in this section of chapter. A PID controller realization is shown in Fig.10. Here, PID controller with one plus-type CCII (CCII+) and one dual-output plus-type CCII (DO-CCII+) are proposed as well as five grounded passive components. Both PID mode controllers do not require any corresponding passive component. To put in another way, each passive element can be arbitrarily selected.

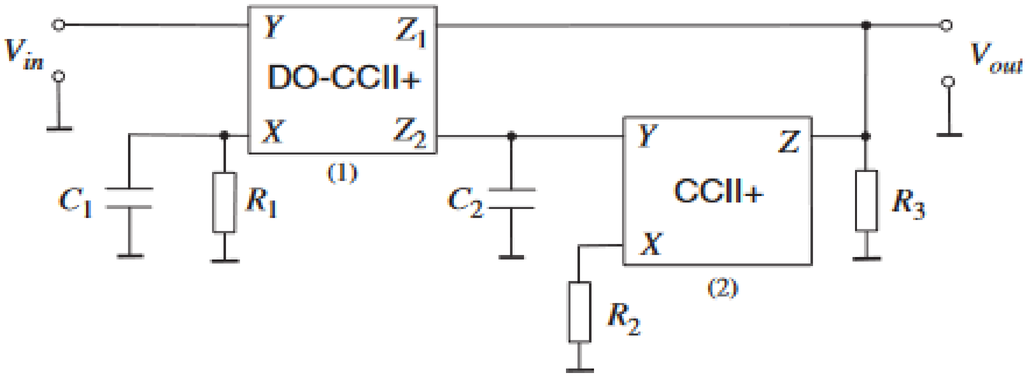

Fig.10 Voltage-mode PID controller realization using CCII [14]

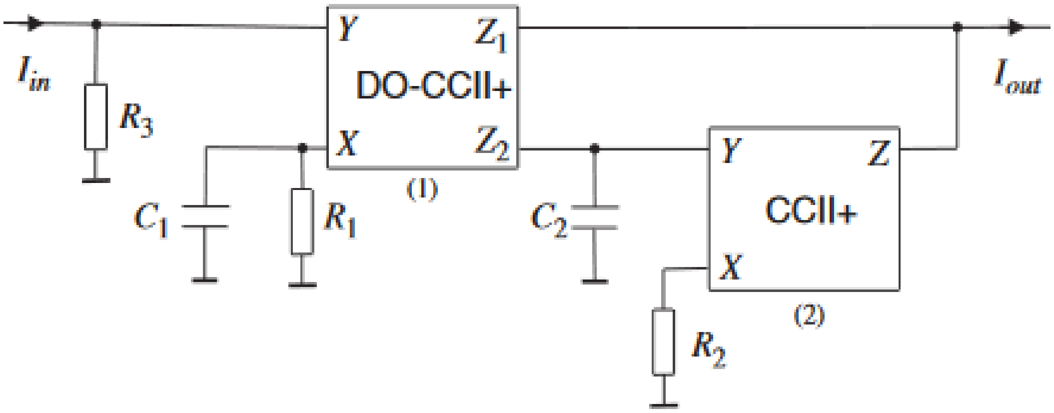

Fig.11 Current-mode PID controller realization using CCII [14]

PID controller parametersK_P, K_I and K_D are -

$$K_P = \frac{R_2 R_8}{R_1 R_3} \tag{6}$$

$$K_I = \frac{R_8}{C_1 R_4 R_5} \tag{7}$$

$$K_D = \frac{R_7}{C_2 R_6 R_8} \tag{8}$$

However, the desired PID controller parameters are difficult to obtain, since the passive element values in the integrated circuit are not easy to adjust and also electronic tunability is not possible in above current conveyor.

2.3 Current Feedback Operational Amplifier (CFOA)

David Nelson invented CFOA at Comlinear Corporation and it was first sold in 1982 as a hybrid amplifier, the CLC103. Recently in few years several CMOS realization for the CFOA has been reported in the literature [15-21]. CFOA came out in existence with using only bipolar processes technology from beginning of the implementation. It is well known for the current sensitivity so that the techniques are inherently well suited to processing signals in the form of current provided by the trans-conductance of the high bipolar junction transistor (BJT).

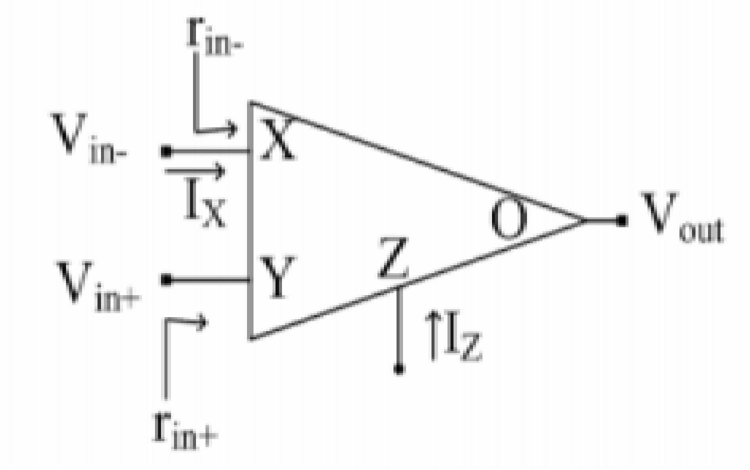

Fig.12 CFOA Block Diagram [15]

CFOA matrix form of expression is given below-

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

A CMOS low voltage current feedback operational amplifier (CFOA) circuit is shown in below Fig.13. It is based on the MOS-transistor technology. This circuit allows almost all input and output operation; also, it helps in reducing the offset voltage and have capabilities to provide high driving current.

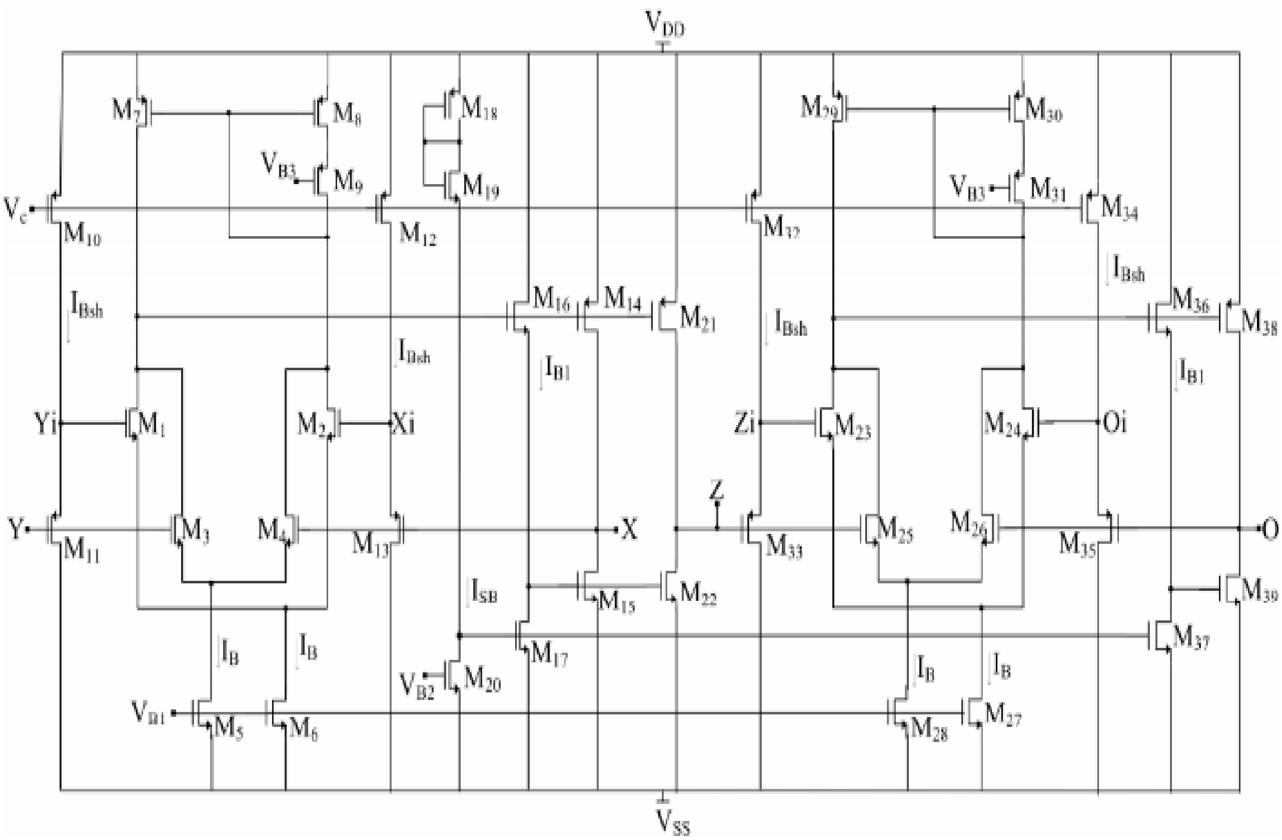

Fig.13 CMOS Realization of CFOA [26]

2.3.1 CFOA Based PID Controller

CFOA active component is the commercially available. PID based CFOA controller uses two resistors and two capacitors and has low impedance voltage output property. This section describes the CFOA based PID controller. Fig.14 shows a CFOA based PID controller.

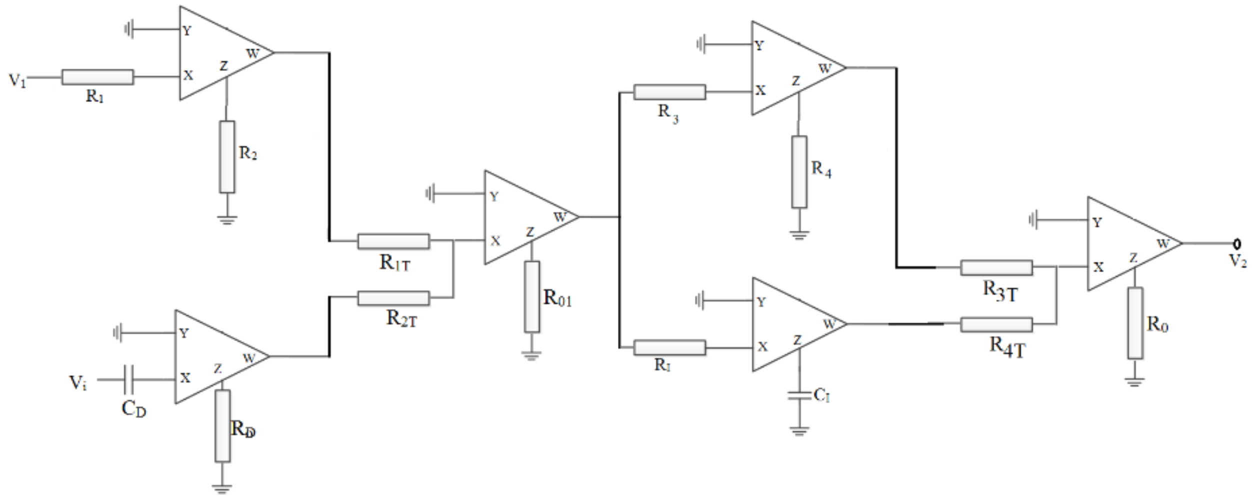

Fig.14 CFOA based PID controller [27].

The controller coefficient or gain are given below

$$K_P = \frac{R_2R_4}{R_1R_3} + \frac{R_DC_D}{R_IC_1} \tag{9}$$

$$K_I = \frac{R_2}{R_1C_1R_I} \tag{10}$$

$$K_D = \frac{R_DC_DR_4}{R_3} \tag{11}$$

Where K_P is proportional gain, K_I is integral gain and K_D is derivative gain of the PID circuit.

However, Conventional Current Feedback Operational Amplifier (CFOA) is neither current controllable nor electronically controllable so it is difficult to realized CFOA based PID controller which required 12 resistors and 2 capacitors.

2.4 Current Differencing Buffered Amplifier (CDBA)

Acar and Ozoguz had introduced current differencing buffered amplifier [28]. It is a four terminal device where p and n is an input terminal and w and z are output terminal as shown in below Fig.15. This outlines the discussion of the variations between the input currents and output voltages. It can operate in both the modes i.e. voltage and current mode, which gives the flexibility to design variety of circuits. Moreover it is free of parasitic capacitance and can operate at high frequency.

Fig.15 CDBA Block Diagram [27]

The characteristic equation of CDBA circuit in matrix form is -

$$\begin{bmatrix} i_Z \\ v_W \\ i_p \\ v_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & \alpha p & \alpha n \\ \beta & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_Z \\ i_W \\ v_p \\ i_n \end{bmatrix}$$

Where αp and αn are current gains and β is voltage gain, ideally equal to 1. The terminal p and n are internally grounded.

CMOS implementation of CDBA is shown below and realized with the help of CMOS bipolar technology [29] by Keskin and Hancioglu where they presented a current mode multifunction using CDBA.

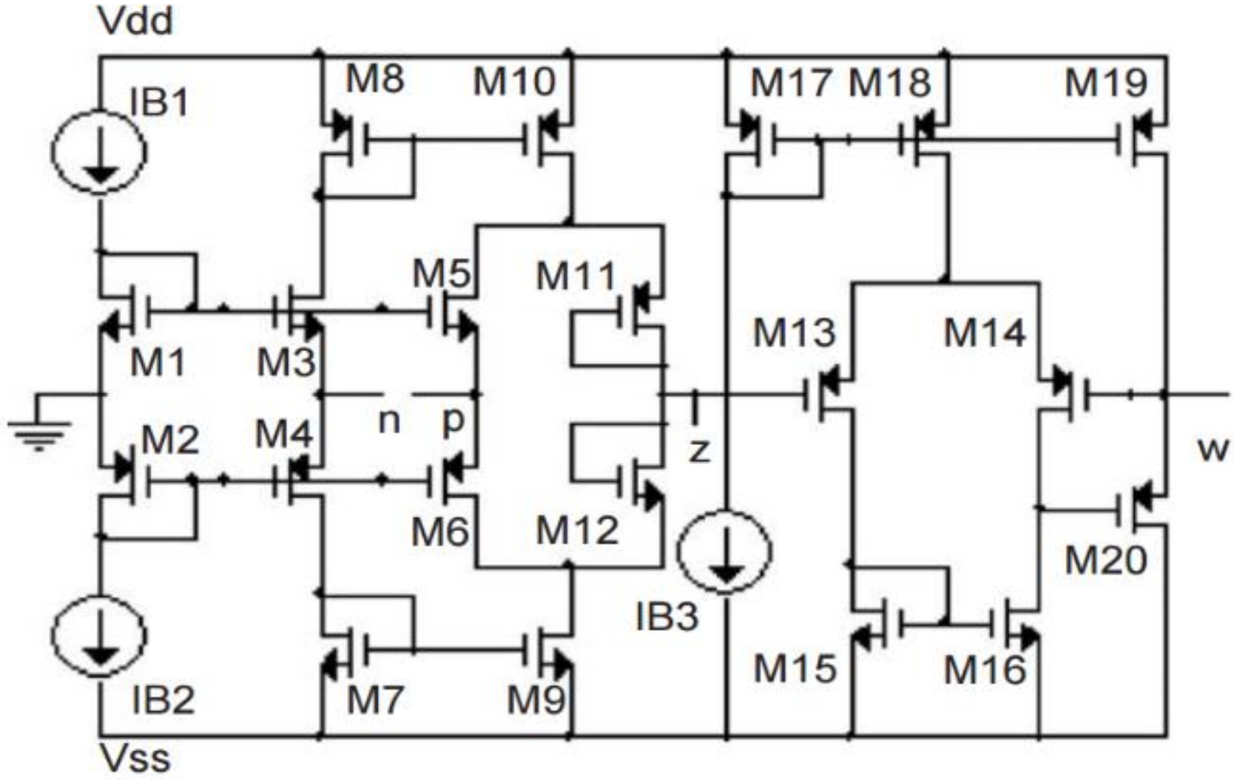

Fig.16 CMOS Realization of CDBA [29]

CMOS realized circuit of CDBA uses a circuit of current differencing (M1-M12) and voltage buffer circuit (M13-M20).

2.4.1 CDBA Based PID Controller

CDBA based PID controller was introduced by Ali Ümit Keskin. In control industry a PID controller is most important control elements. Almost half of the industrial controller utilizes PID control schemes. Due to the reduced number of parameters to be tuned it is used in industrial control systems. The below Fig.17 shows PID controller using CDBA

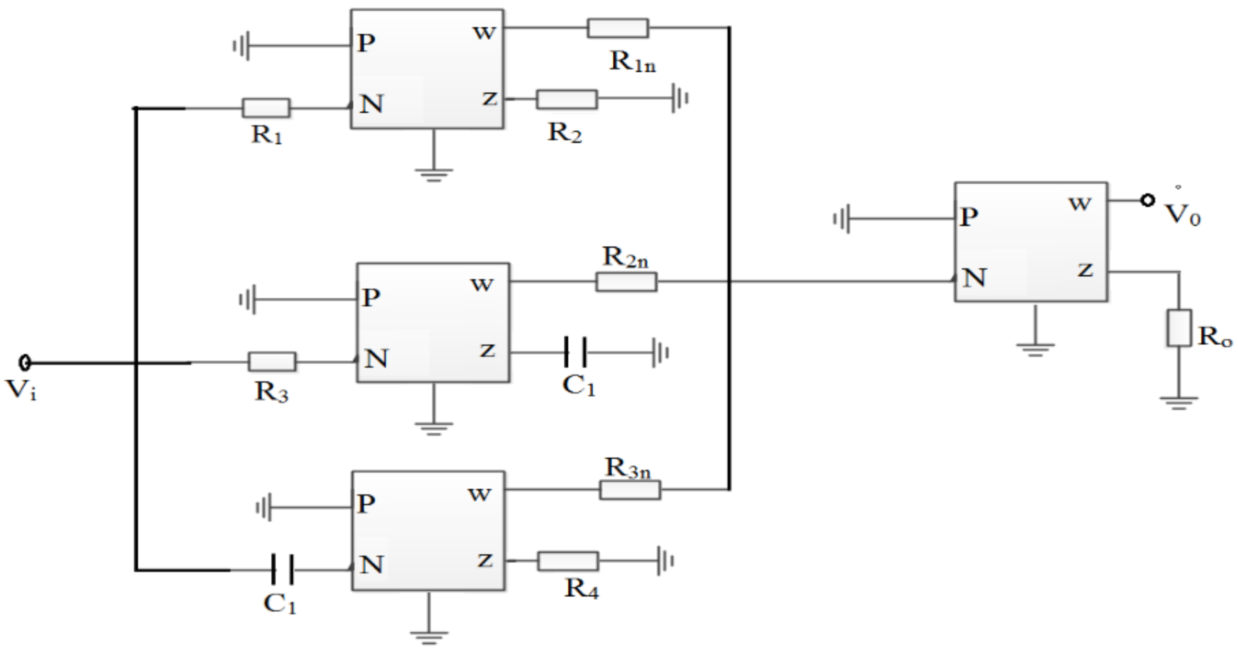

Fig.17 CDBA based PID controller [30].

The coefficients of PID controller are given below-

$$K_P = \frac{R_0 R_2}{R_1 R_{1n}} \tag{12}$$

$$K_I = \frac{R_0}{R_3 C_1 R_{2n}} \tag{13}$$

$$K_D = \frac{R_0 C_2 R_4}{R_{3n}} \tag{14}$$

The major disadvantage of PID controller using CDBA is its electronic tunability and low output impedance of CDBA circuit. Also it requires large number of passive elements.

2.5 Voltage differencing transconductance Amplifier (VDTA)

For realizing the voltage difference, the differential input of OTA is a simple element. The VDTA block is shown in below Fig.18. The input terminal p and n of VDTA exhibits high impedance, and it has an auxiliary terminal Z. It multiple copies of current I_{Z_c} in order to increase the universality of VDTA element that's represent a new terminal Z_c (Z Copy)[31]. An ideal VDTA has high input and output impedance.

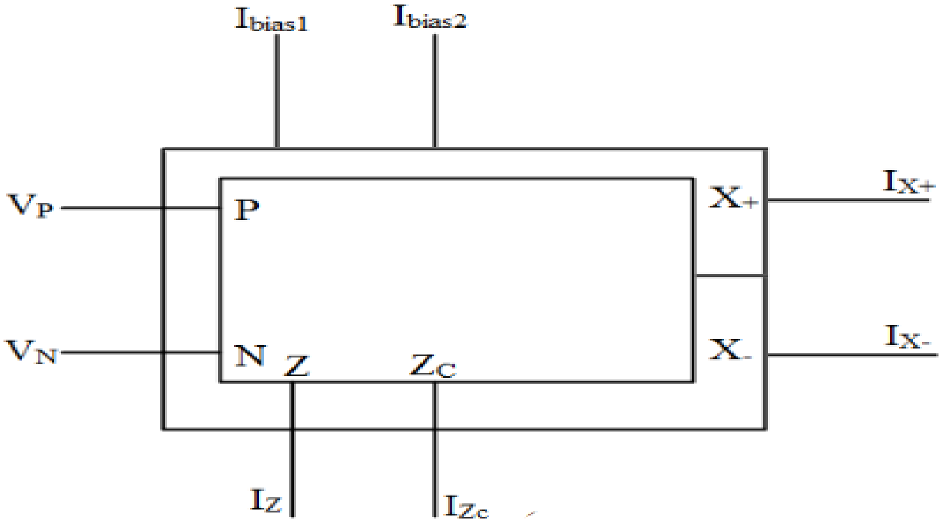

Fig.18 VDTA Block Diagram [31]

The characteristic equation in matrix form of VDTA block–

$$\begin{bmatrix} I_Z \\ I_Z^+ \\ I_Z^- \end{bmatrix} = \begin{bmatrix} g_{m_1} & -g_{m_2} & 0 \\ 0 & 0 & g_{m_1} \\ 0 & 0 & -g_{m_2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix}$$

Where the first and second transconductance parameter of VDTA is g_{m_1} and g_{m_2} which is controlled by bias current I_{bias} of VDTA.

Abdullah Yesil, Fırat Kacar, Hakan Kuntman presented a RF filter based on VDTA [31]. In that paper they realized VDTA with the help of CMOS bipolar technology. The Fig.19 shows CMOS implementation of VDTA where there are four bias current for tunability.

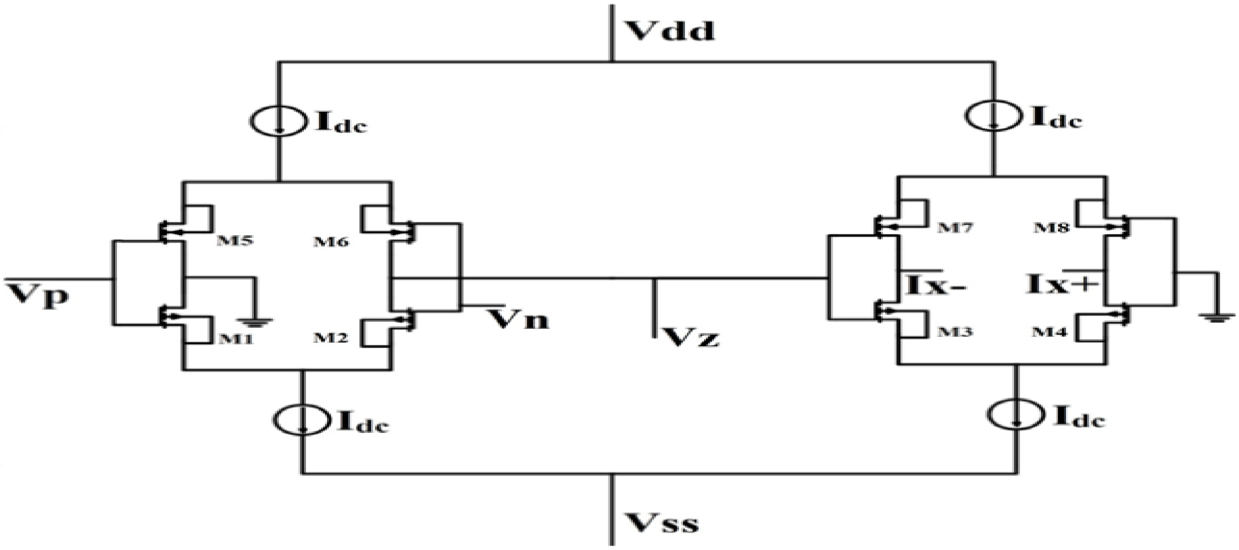

Fig.19 CMOS Realization of VDTA [31]

2.5.1 VDTA based PID controller

The PID controller is the most practical controller used for industrial or plant applications. In the field of process control systems, the basic and modified PID control scheme have proved their usefulness in providing adequate control, although they may not provide optimum control in many situations. A VDTA based PID circuit is shown below

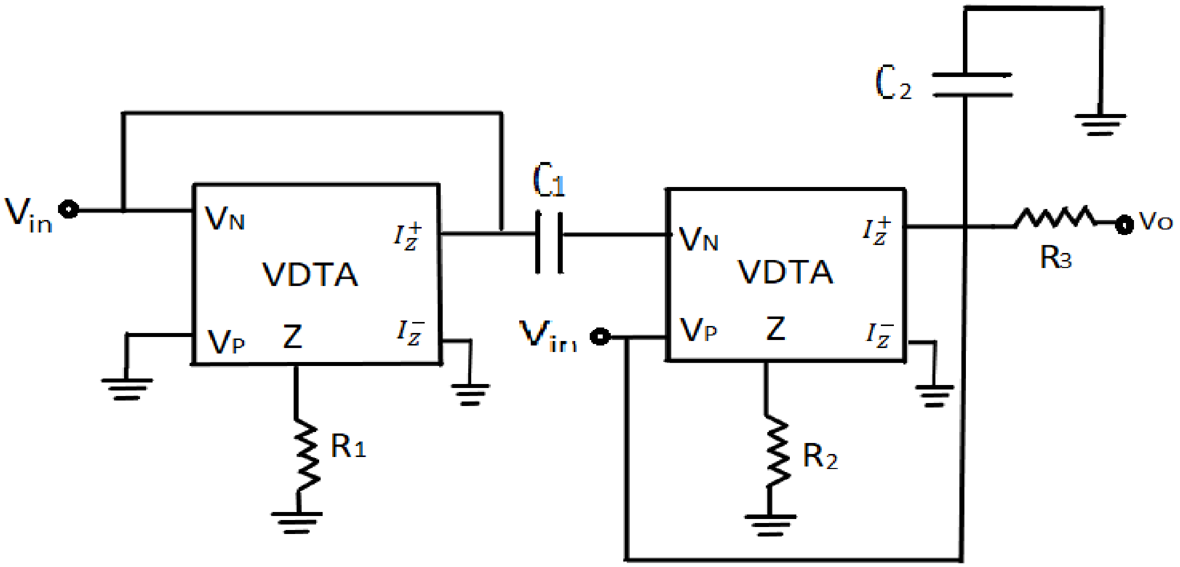

Fig.19 VDTA based PID controller [32]

PID controller coefficients are given as-

$$K_P = 1 \tag{14}$$

$$K_I = \frac{g_{m_1}^2 g_{m_2}^2 R_1 R_2 R_3}{C_1} \tag{15}$$

$$K_D = C_2 R_3 \tag{16}$$

The problem with VDTA based PID controller is the floating capacitor and the proportional gain is unity.

CHAPTER 3

VOLTAGE DIFFERENCING CURRENT CONVEYOR

3.1 Introduction

Voltage Differencing Current Conveyor (VDCC) is an active building block which was introduced for the first time by Biolek, Senani, Biolkova and Kolka [33]. The CMOS implementation of this block has been proposed by Kacar, Yesil, Minaei and Kuntman [34].

In this chapter we will discuss the VDCC active block in detail and this forms the base for the further work done in this thesis in the field of application of VDCC active block. Using PSPICE the complete characterization of VDCC using 0.18μm CMOS technology has been presented. PSPICE simulations were conducted to verify the functionality of the block.

3.2 Circuit Description

The circuit symbol of VDCC block is shown in Fig 20, where p and n are input terminals and z, x, W_p and W_n are the output terminals of VDCC block.

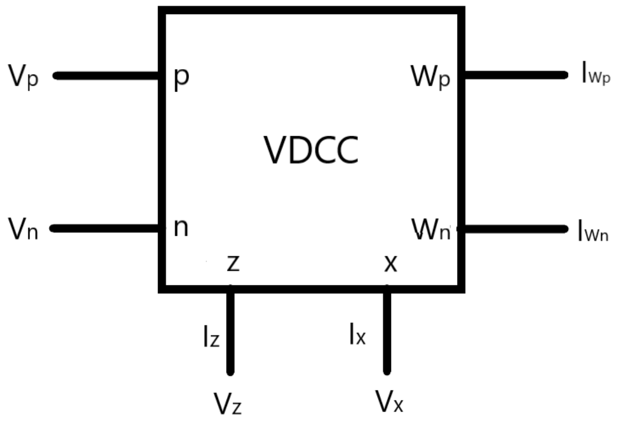

Fig 20- Symbol of VDCC [34]

All of the terminals of VDCC block exhibit high impedance, except the x terminal.

$$\begin{bmatrix} I_n \\ I_p \\ I_z \\ V_x \\ I_{W_p} \\ I_{W_n} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \\ I_x \end{bmatrix}$$

According to the above matrix equation, the first stage of VDCC circuit is a balance transconductance amplifier which is used to transform the difference of the input voltages ($V_p - V_n$) into the output current I_z with g_m transconductance gain and a current conveyor used at second stage to pass x-terminal current to W_p and W_n terminals. Input and output relationship of Ideal VDCC is

$$I_z = g_m\left(V_p - V_n\right) \tag{17}$$

$$V_x = V_z \tag{18}$$

$$I_{w_p} = I_x \tag{19}$$

$$I_{w_n} = -I_x \tag{20}$$

Here transconductance gain g_m is controlled by bias current I_B , C_{ox} - Gate oxide capacitance per unit area, μ- mobility, $\frac{W}{L}$ - Aspect ratio.

The realization of VDCC circuit based on CMOS structure is shown in Fig.21. The Volatge supplies and biasing currents used for the simulation are given by $V_{DD} = -V_{SS} = 0.9$, $I_{B_1} = 50\mu A \ and \ I_{B_2} = 100\mu A$, respectively. The transistor’s aspect ratios are given in Table 1. TSMC CMOS $0.18\mu m$ process model parameters are used in circuit simulation [34].

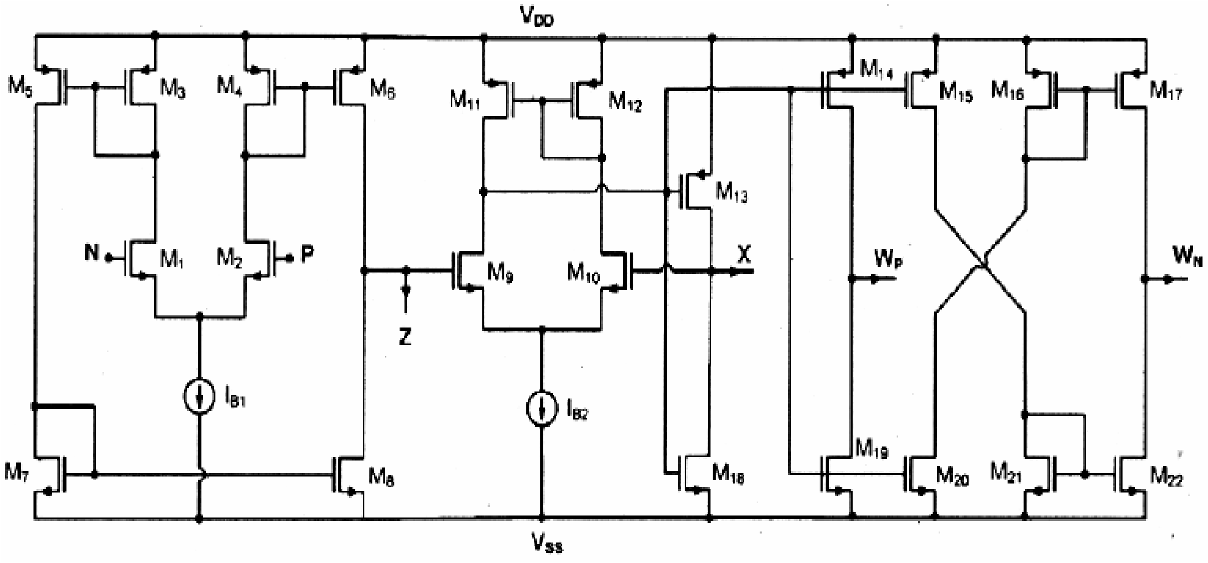

Fig 21-CMOS implementation of VDCC [34]

Table 1-Transistor aspect ratios for the VDCC of Fig.21 [34]

TRANSISTORS	$W/L\ (\mu m)$
M_1 –M_4	3.6/1.8
M_5 –M_6	7.2/1.8
M_7 –M_8	2.4/1.8
M_9 –M_{10}	3.06/0.72
M_{11} –M_{12}	9/0.72
M_{13} –M_{17}	14.4/0.72
M_{18} –M_{22}	0.72/0.72

CHAPTER 4

PROPOSED PI, PD AND PID CONTROLLER USING VDCC

The traditional PID controller has a rather basic structure and is used for control of different or various process parameters in a number of process control system. The conventional PID controller was manufactured with typical operational amplifiers in the voltage mode and thus suffers many disadvantages viz. low speed, limited bandwidth, low dynamic range and also conflict in gain bandwidth. Because of its wider bandwidth, improved linearity, lower voltage operation and stability properties of current mode devices compared to its contrast Voltage mode circuits are getting broad attention. Many devices have been used to implement PID controllers as explained in Chapter 3.

4.1 Synthesis of PID controller

The general transfer function of a PID controller is -

$$H(s) = \frac{V_{out}}{V_{in}} = K_p + \frac{K_I}{s} + sK_D \tag{21}$$

Here K_p, K_I and K_D are the controller gain coefficients of PID controller.

4.1.1 Proportional controller

Proportional defines with variable time for present error values that means the controller output will also be large and positive for the large and positive error. Proportional output voltage or current of the controller follows input voltage or current supplied with a gain value depending on the elements connected to the active block.

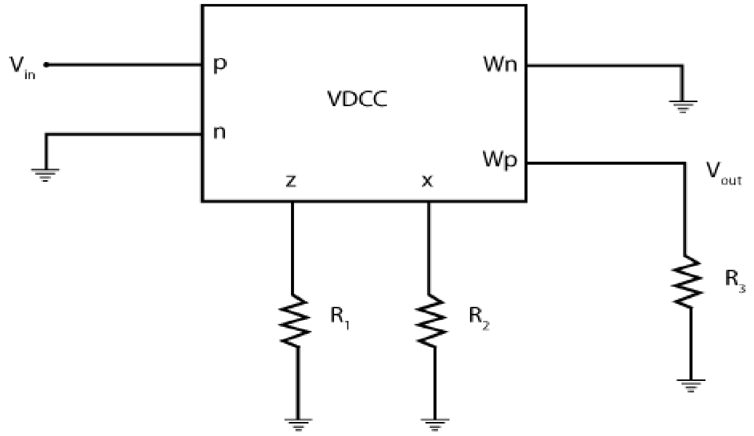

Fig.22 Proportional controller using VDCC

The transfer function of Proportional controller -

$$\frac{V_{out}(s)}{V_{in}(s)} = K_P = \frac{g_m R_1 R_3}{R_2} \tag{22}$$

Here g_m is transconductance of VDCC and K_P is proportional gain of the circuit.

4.1.2 Integral controller

Integral controller is used for reducing error in control system. In this, control exertion is proportional to the integration of error. By utilizing the VDCC circuit operation of integration can be accomplished successfully.

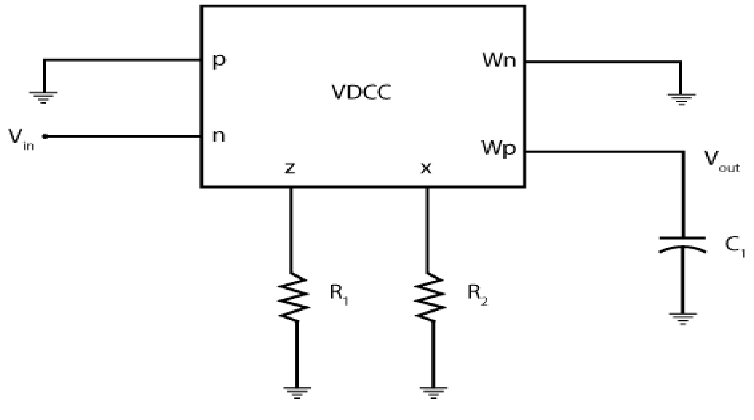

Fig.23 Integral controller using VDCC

The transfer function of Integral controller-

$$\frac{V_{out}(s)}{V_{in}(s)} = K_I = \frac{-g_m R_1}{sC_1 R_2} \tag{23}$$

Here g_m is transconductance of VDCC and K_I is the Integral gain or coefficient of the circuit.

4.1.3 Derivative controller

By finding the error's slope over time and multiply derivative gain with rate of change gives the process error of derivative. And derivative gain is defined as the magnitude of the derivative rate to the control action. It improves behavior of the system and settling time and also improves system stability.

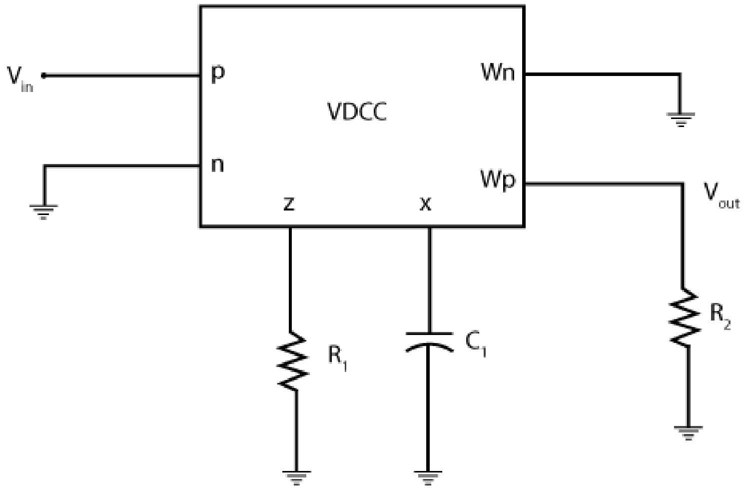

Fig.24 Derivative controller using VDCC

The transfer function of Derivative controller –

$$\frac{V_{out}(s)}{V_{in}(s)} = K_D = g_m sC_1 R_2 R_3 \tag{24}$$

Here g_m is transconductance of VDCC and K_D is the Derivative gain or coefficient of the circuit.

4.1.4 PI Controller

To reach steady state proportional controller takes lesser time but it also gives larger peak overshoot and thus exhibits a residual error which decreases efficiency of the plant. On the other hand Integral controller reduces error up to 0 but to reach at steady state it takes more time. Thus the implementation of a proportional and Integral controller helps the plant to operate in more efficient manner and decreased the time required to achieve a stable state by reducing the steady state error. The proposed PI controller using VDCC is shown in below figure.

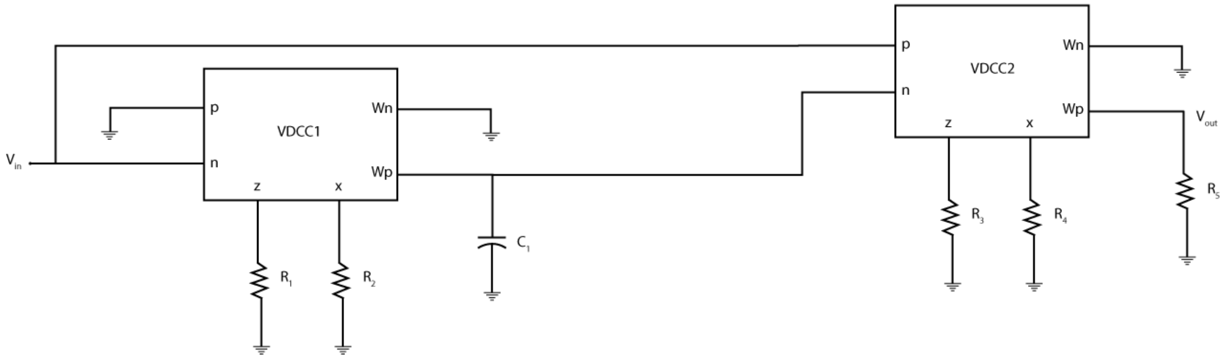

Fig.25 Proposed PI controller using VDCC

The transfer function of Proposed PI controller –

$$\frac{V_{out}(s)}{V_{in}(s)} = \left(K_P + \frac{K_I}{s}\right) \qquad (25)$$

Or

$$\frac{V_{out}(s)}{V_{in}(s)} = K_P \left(1 + \frac{1}{sT_I}\right) \qquad (26)$$

Where $K_P = \frac{g_m R_3 R_5}{R_4}$ (27)

$K_I = g_m^2 \frac{R_1 R_3 R_5}{R_2 R_4 C_1}$ (28)

Hence when we use this circuit with any second order system, the Integral controller removes steady state error while proportional controller operation in response to input stabilizes the system.

As T_I increases

- Overshoot becomes smaller
- Response Speed becomes slower

4.1.5 PD Controller

PD controller incorporates Proportional and derivative controller in order to get better response. The controller derivative action acts on the derivative or rate of change of error. In comparison to integral action it offers faster response but cannot tolerate constant errors. The proposed PD controller using VDCC is shown in below figure.

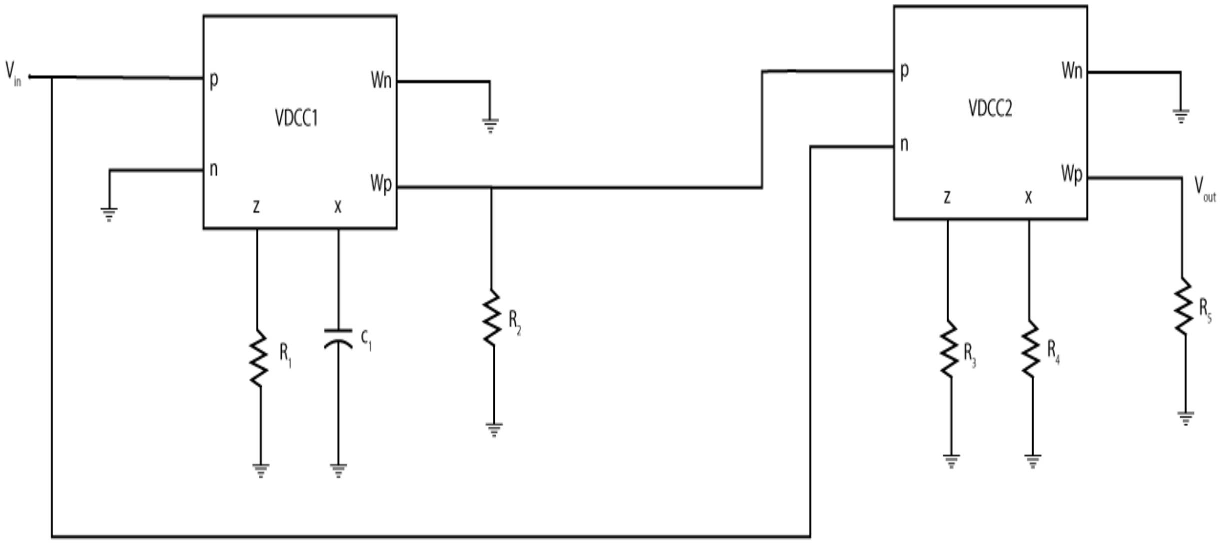

Fig.26 Proposed PD controller using VDCC

Proposed PI controller transfer function is –

$$\frac{V_{out}(s)}{V_{in}(s)} = (K_P + sK_D) \tag{29}$$

Or

$$\frac{V_{out}(s)}{V_{in}(s)} = K_P\ (1 + sT_D) \quad (30)$$

Where $K_P = \frac{g_m R_3 R_5}{R_4}$ (31)

$$K_D = g_m^2\ \frac{C_1 R_1 R_2 R_3 R_5}{R_4} \quad (32)$$

In the above equations we can conclude that if we increase T_D

- Overshoot tends to become smaller
- Rise time becomes slower but settling time remains same.

4.1.5 PID Controller

The most practical and popular controller used in an industry is Proportional-Integral-Derivative controller i.e. PID controller. Because of its general applicability it is used in most process control system [35]. It is well known that the simple and revised PID control scheme has proved useful in providing adequate control, although in many situations it does not provide optimum control.

To implement a PID controller we must satisfy the following transfer function-

$$H(s) = \frac{V_{out}}{V_{in}} = K_p + \frac{K_I}{s} + sK_D \quad (33)$$

Where K_p = Proportional constant

K_I = Integral controller

K_D = Derivative controller

In order to get output with the following nature listed below we use PID controller-

- Proportional Coefficient at instant t is proportional to the error, this is the present error.
- Integral Coefficient is proportional to the error integral up to t, can be defined as the past error accumulation.

- Derivative Coefficient at instant t is proportional to the derivative error, can be defined as the future error prediction.

The proposed PID controller using VDCC is shown in below figure and simulation result is presented in next chapter.

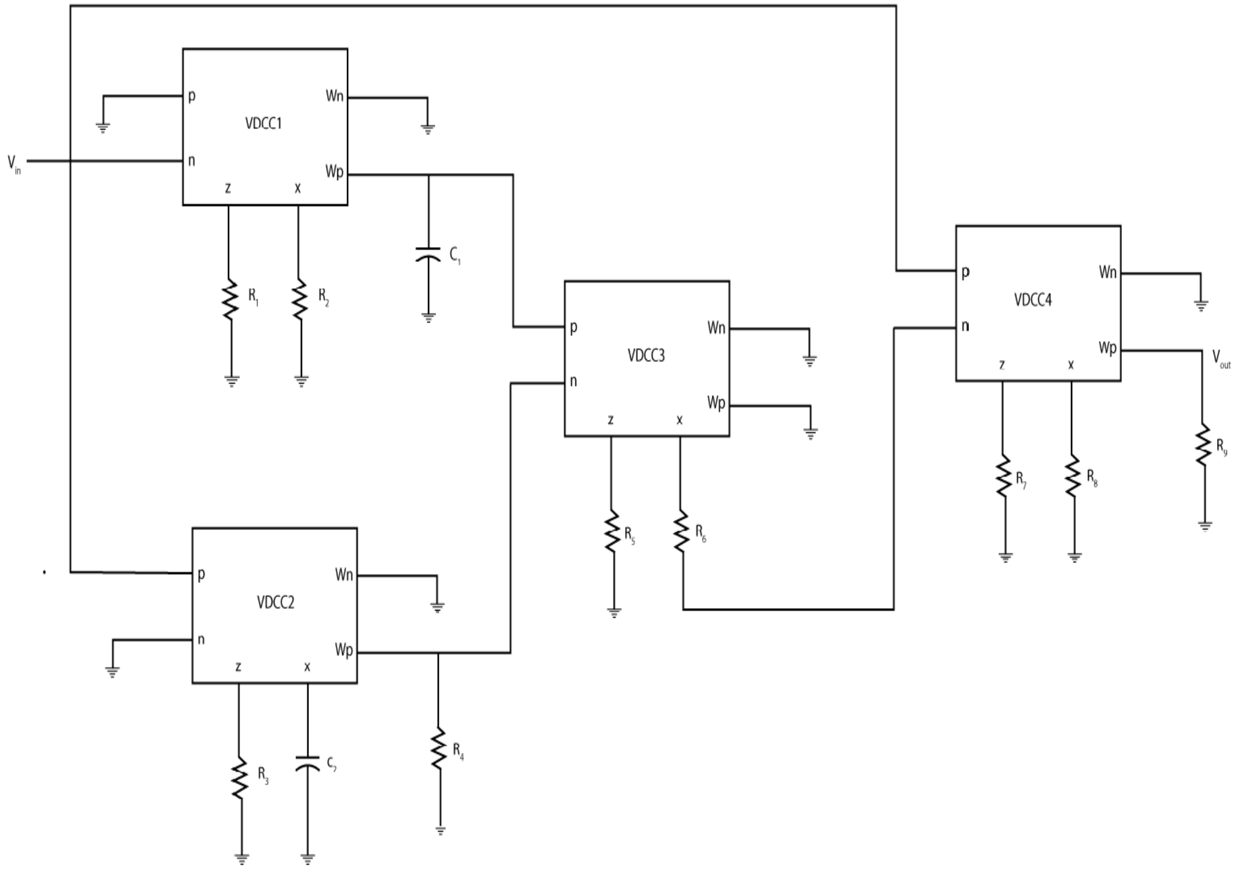

Fig.27 Proposed PID controller using VDCC

The Proposed PID controller transfer function using VDCC block is -

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{g_m R_7 R_9}{R_8}\left(1 + \frac{g_m^2 R_1 R_5}{s C_1 R_2} + g_m^2 s C_2 R_3 R_4 R_5\right) \qquad (34)$$

Where $K_P = \frac{g_m R_7 R_9}{R_6}$ (35)

$$K_I = \frac{g_m^3 R_1 R_5 R_7 R_9}{C_1 R_2 R_8} \qquad (36)$$

$$K_D = \frac{g_m^3 C_2 R_3 R_4 R_5 R_7 R_9}{R_8} \tag{37}$$

Tuning of PID controller can be done by changing the bias current of VDCC block without affecting the grounded passive elements. In the above PID controller BLOCK1 is integral block, BLOCK2 is derivative block and combination of BLOCK1 and BLOCK 4 is PI controller. Similarly BLOCK2 and BLOCK4 is PD controller.

CHAPTER 5

SMULATION RESULTS

5.1 Simulation of VDCC block

The theoretical validity of the VDCC is verified by simulating the structure with the help of PSPICE program as shown in below figure. The VDCC block simulation is performed using the $0.18\mu m$ TSMC process parameters [12]. In Table 1, MOS transistors aspect ratio is given. The supply voltages are selected as $V_{DD} = -V_{SS} = 0.9\,, I_{B_1} = 50\mu A \; and \; I_{B_2} = 100\mu A$. By using these values $g_m = 277\ \mu A/V$ is calculated.

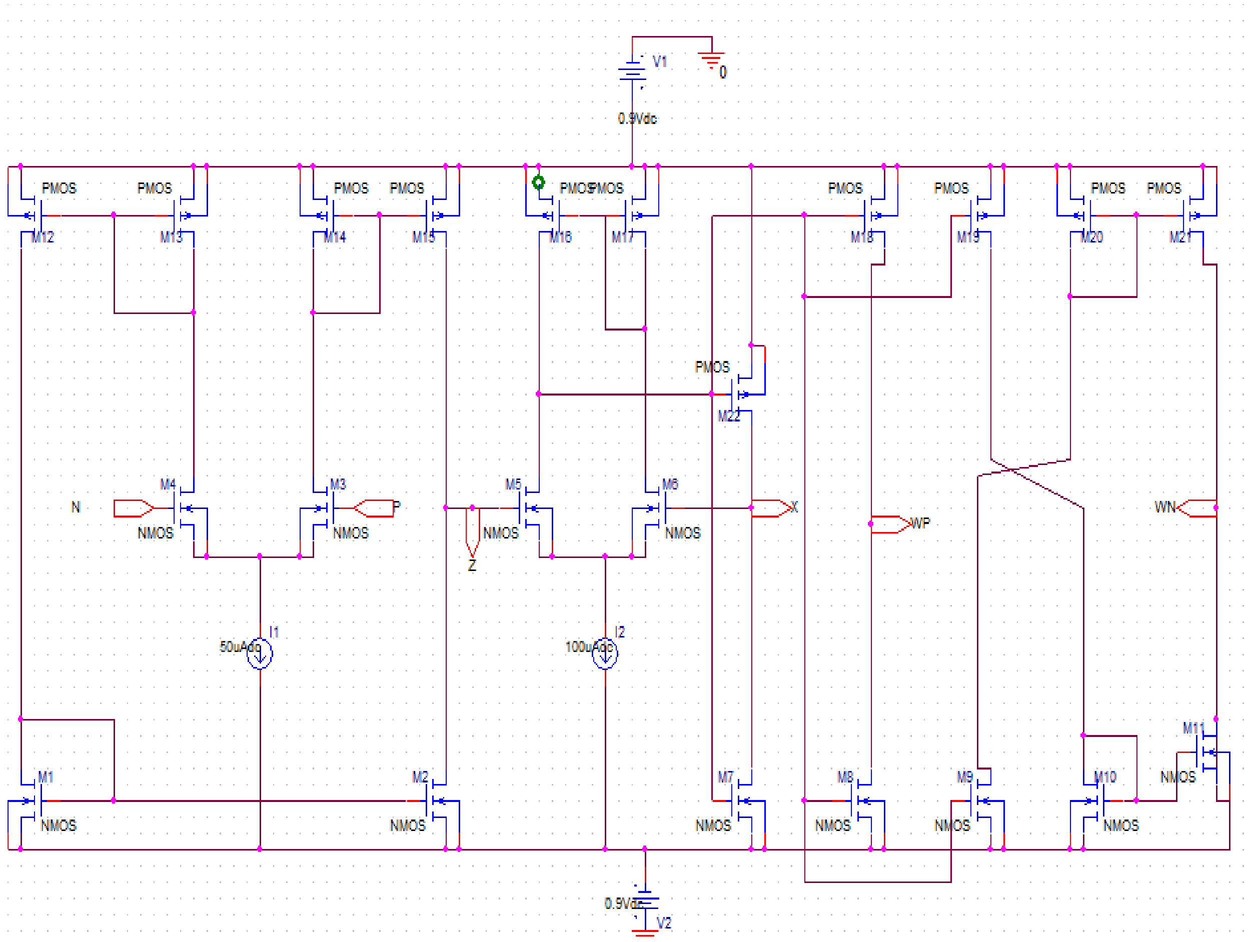

Fig.28 MOS structure of VDCC in PSPICE

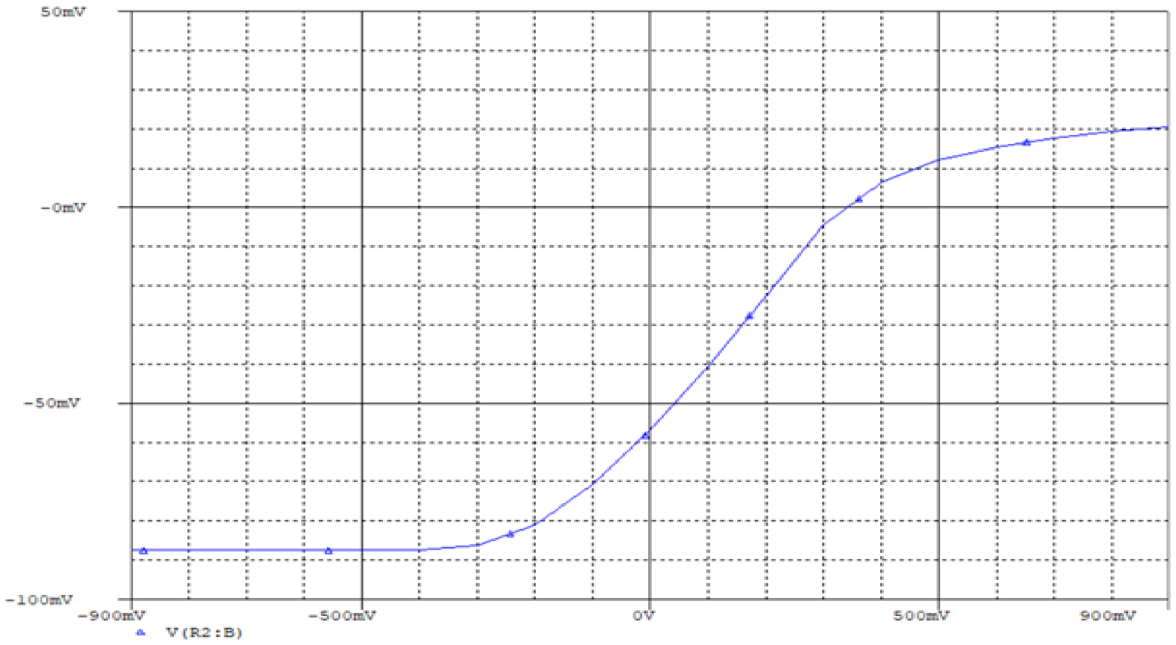

Fig.29 DC characteristic of V_z terminal of VDCC

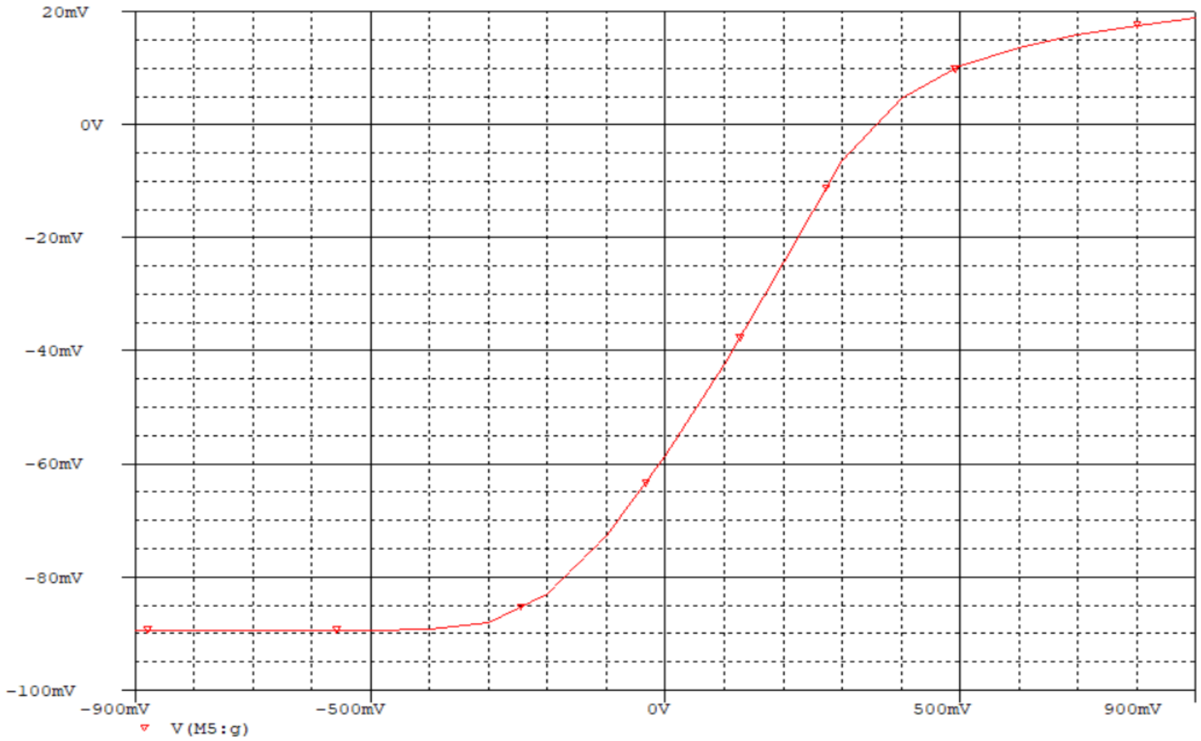

Fig.30 DC characteristic of V_x terminal of VDCC

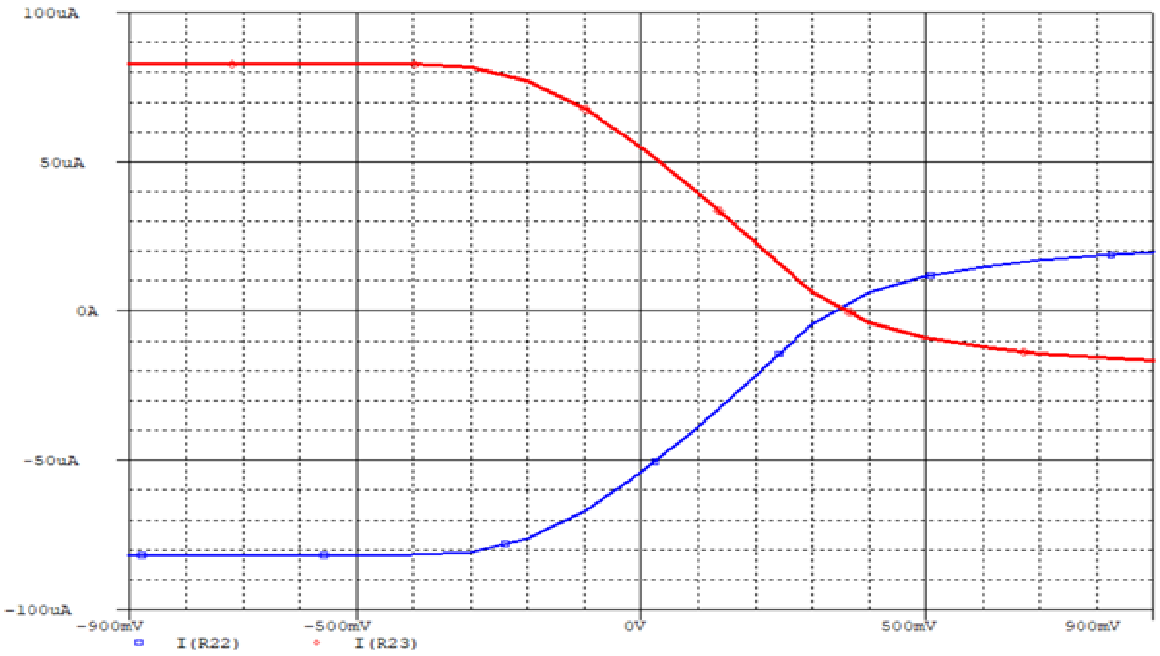

Fig.31 Output DC characteristic of VDCC

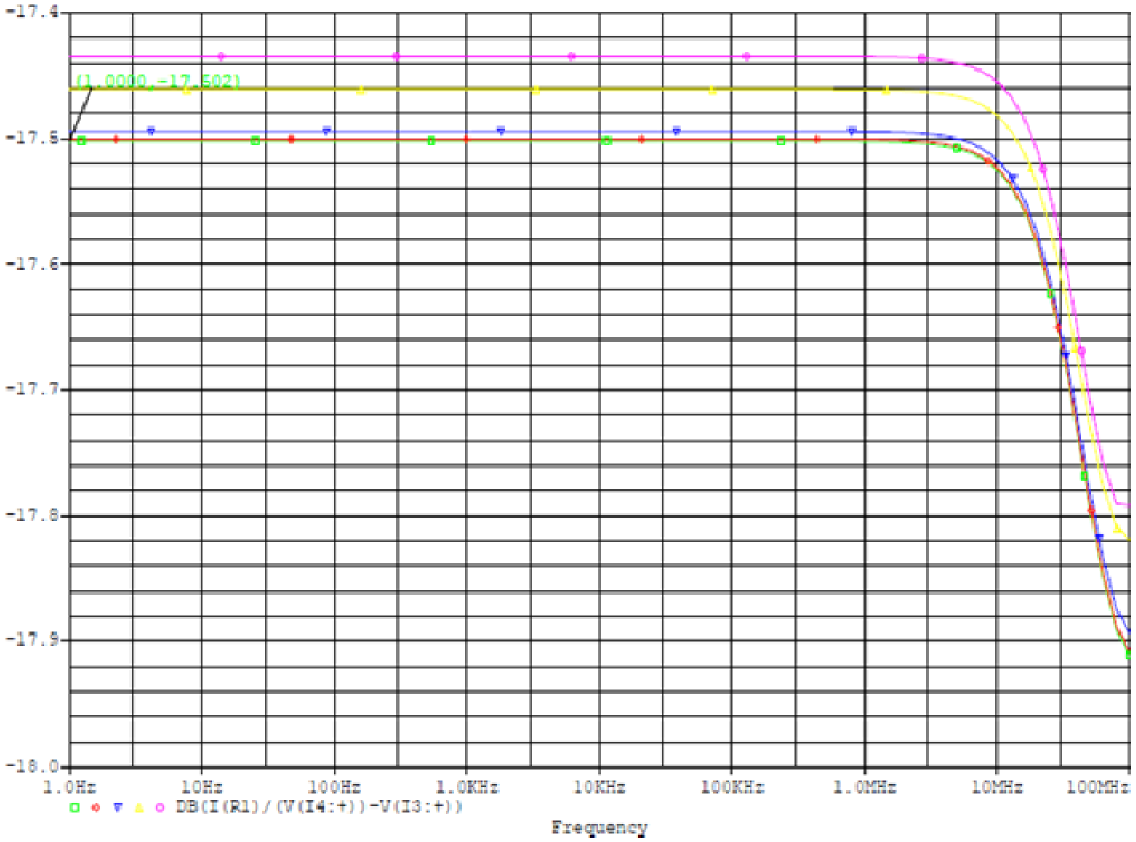

Fig.32 g_mv/s frequency Curve (VDCC)

The theoretical validity of proportional, integral, derivative, PI, PD and PID using VDCC is verified by simulating the structure with the help of PSPICE program.

5.2 Simulation of Proportional Controller

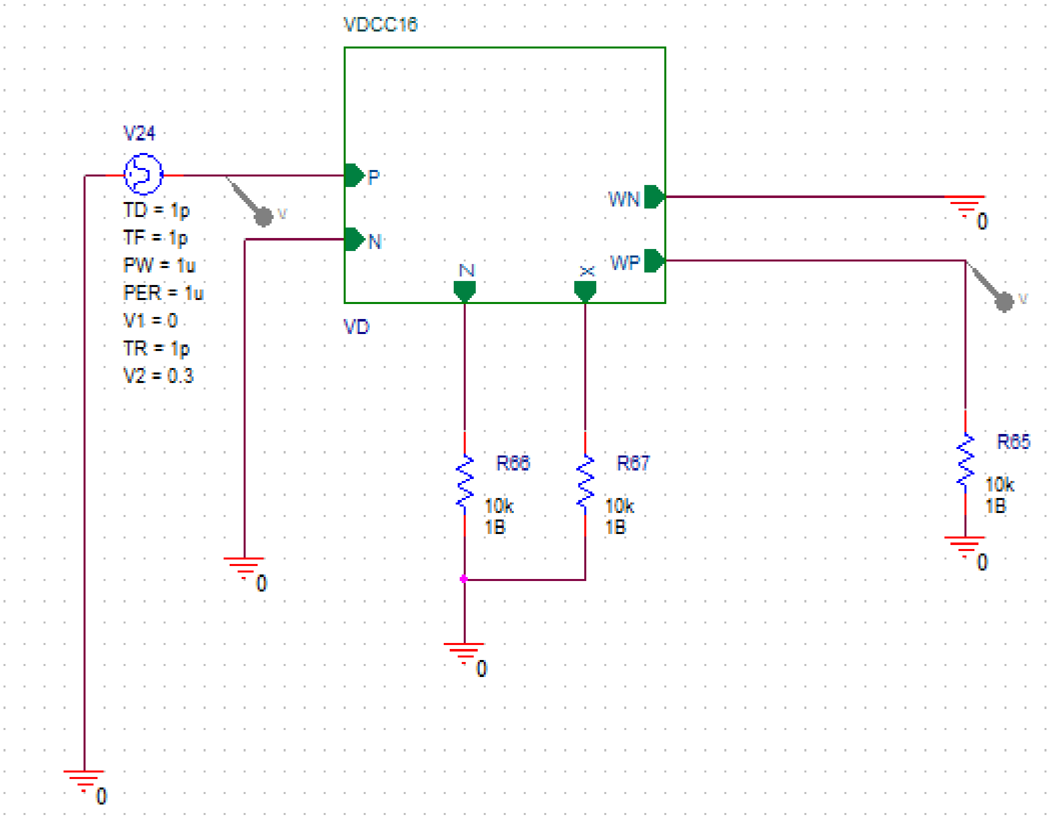

Fig.33 Proportional controller using VDCC block in PSPICE

Taking values of $R_{66} = R_{65} = R_{67} = 10\ kohm$ and $g_m = 277\mu A/V$ so that it gives a gain value $K_P = 2.77$. The simulated output is shown in below figure.

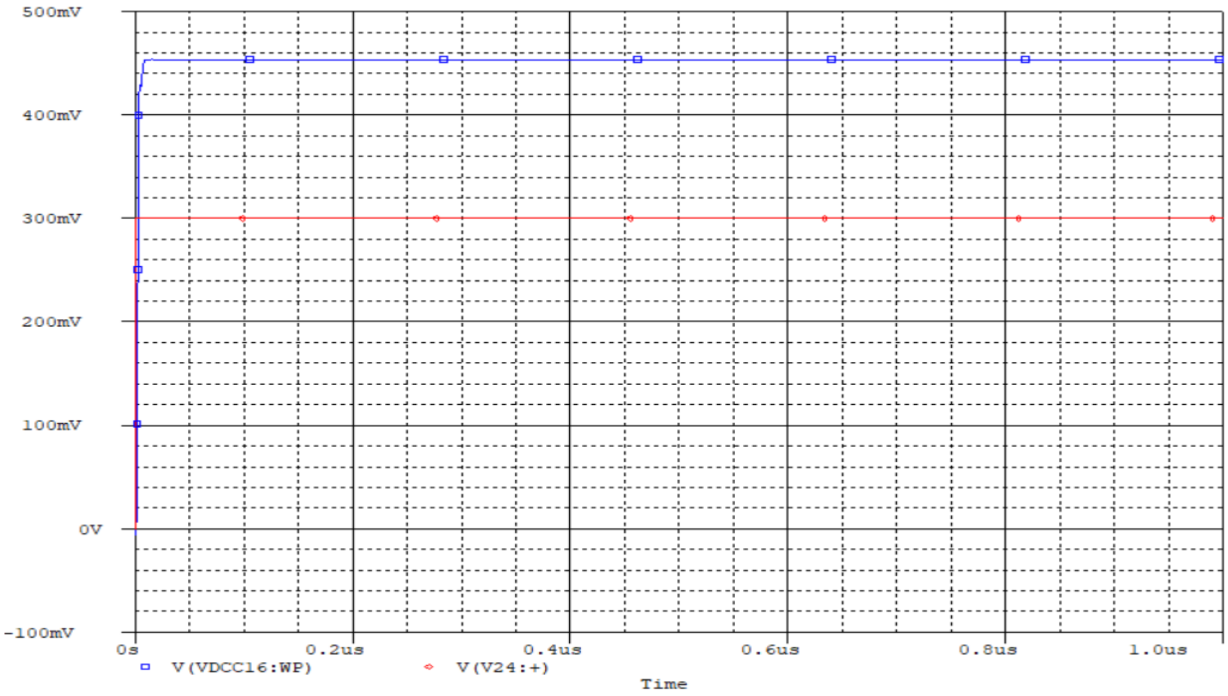

Fig.34 Step response of Proportional controller

5.3 Simulation of Integral Controller

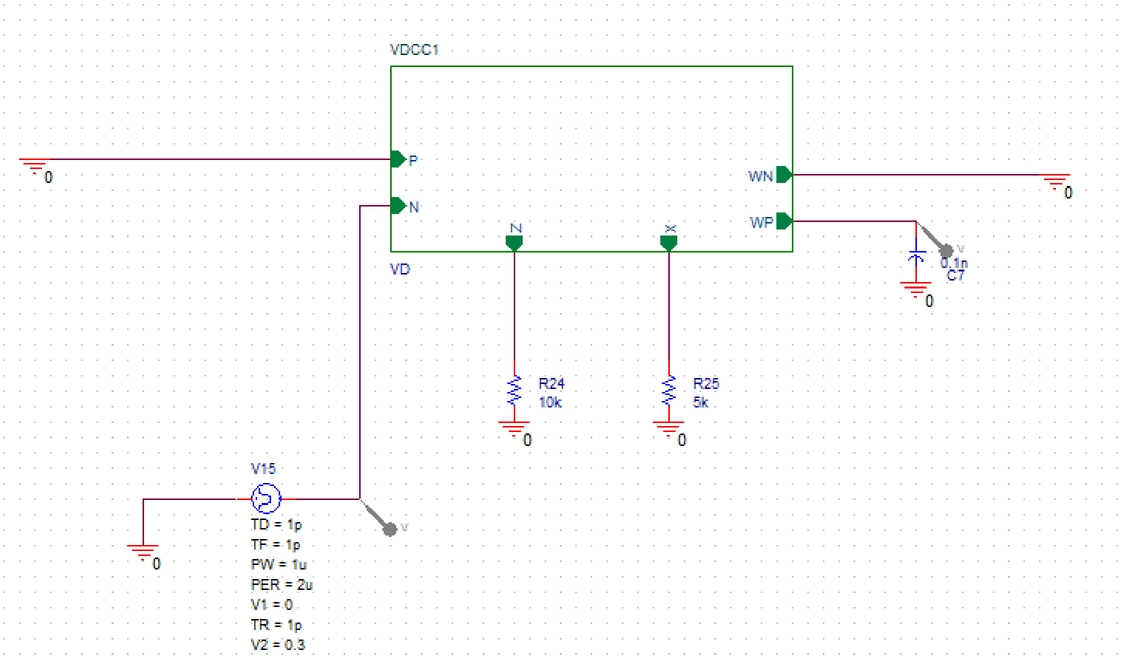

Fig.35 Integral controller using VDCC block in PSPICE

From the above circuit the value of $K_I = 5.5 * \ 10^6$ is calculated.

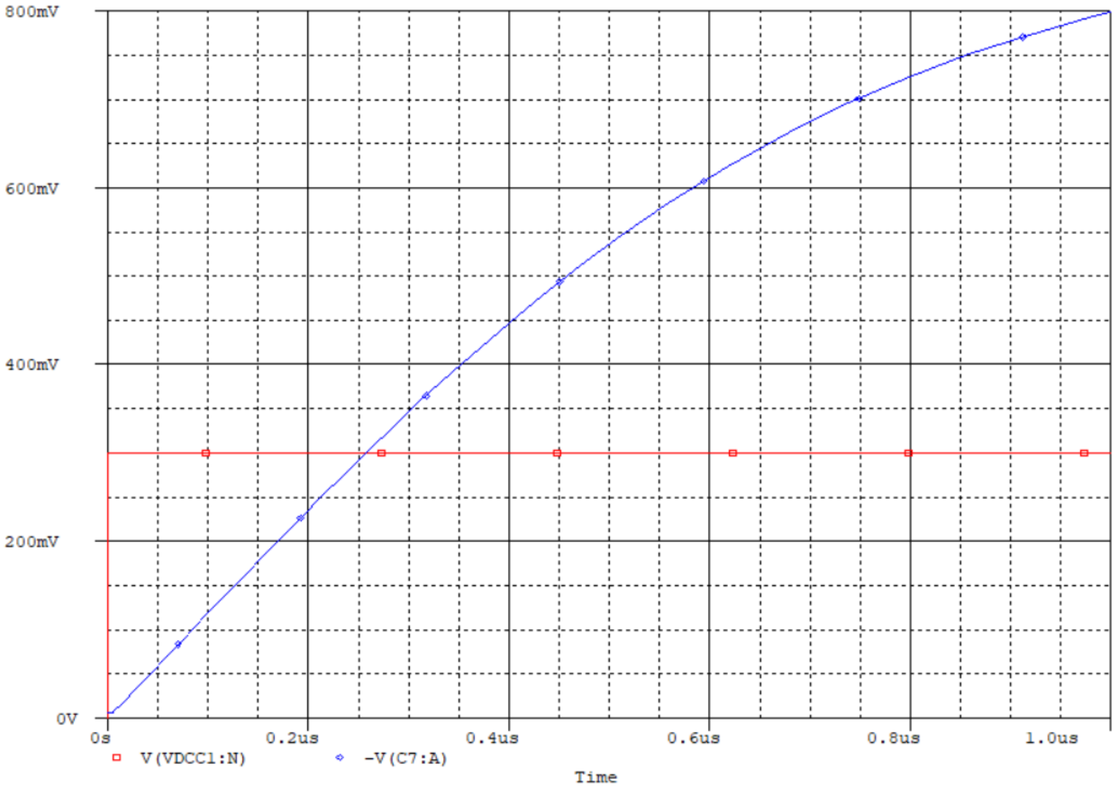

Fig.36 Step response of Integral controller

5.4 Simulation of Derivative Controller

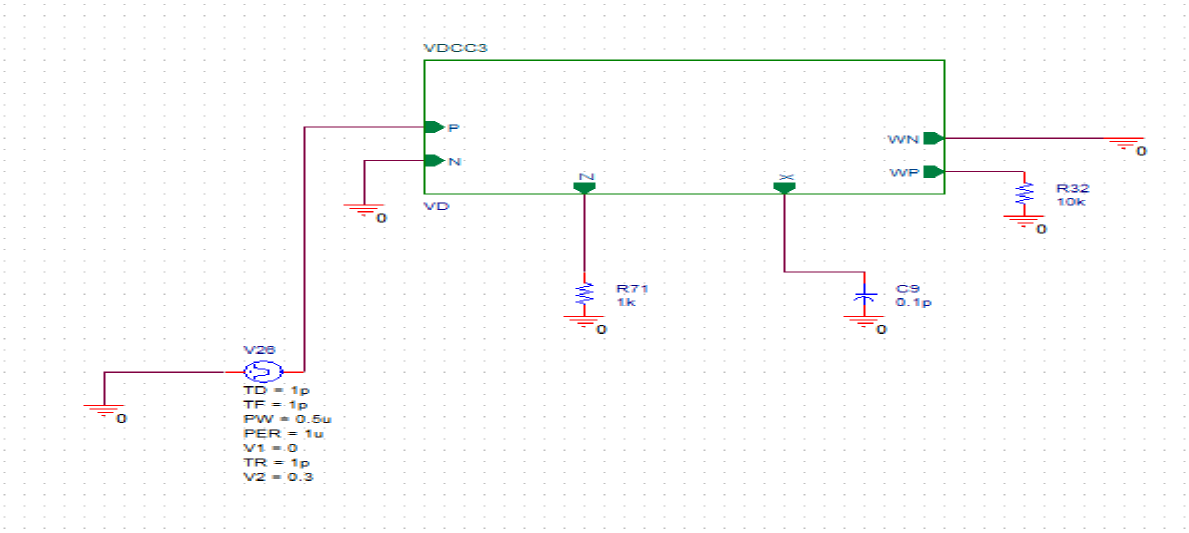

Fig.37 Derivative controller using VDCC block in PSPICE

From the above circuit the value of $K_D = 0.277 * 10^{-9}$ is calculated.

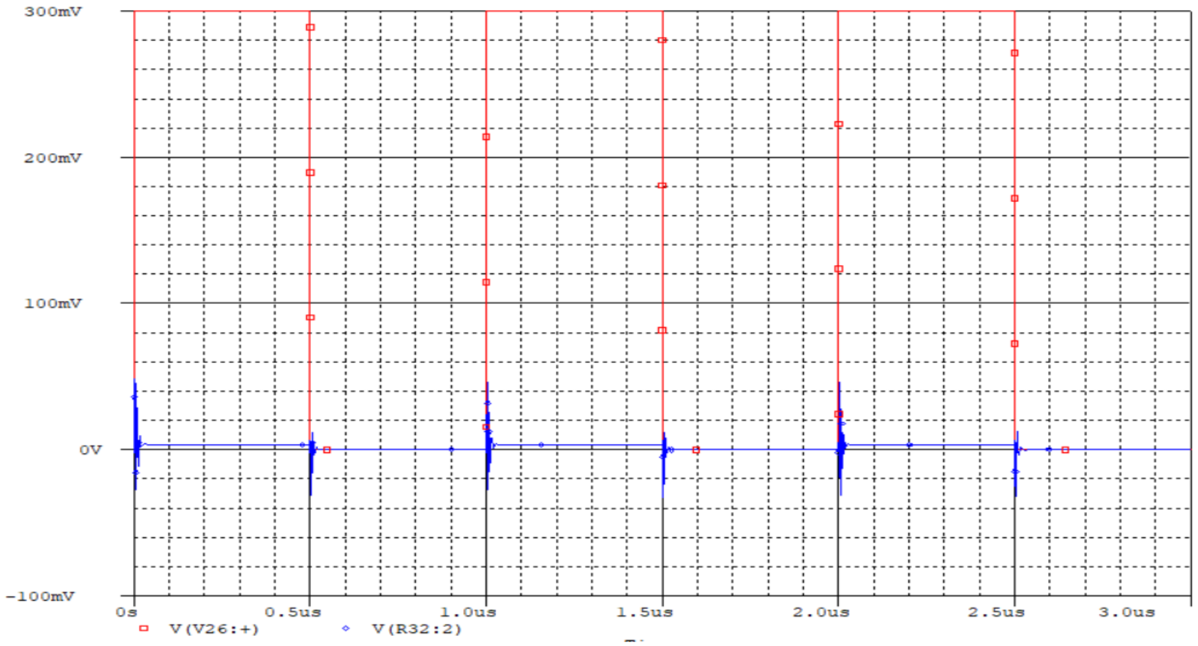

Fig.38 Step response of Derivative controller

5.5 Simulation of Proportional-Integral or PI Controller

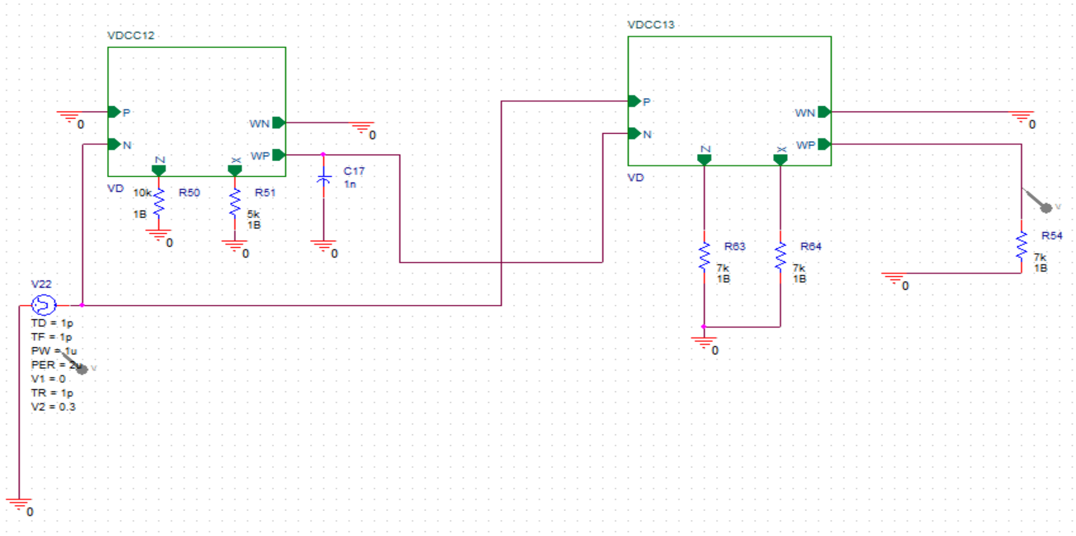

Fig.39 PI controller using VDCC block in PSPICE

The stimulated output of PI controller for a step input is shown in below figure with $K_P = 1.939$ and $K_I = 1.07 * 10^6$ respectively.

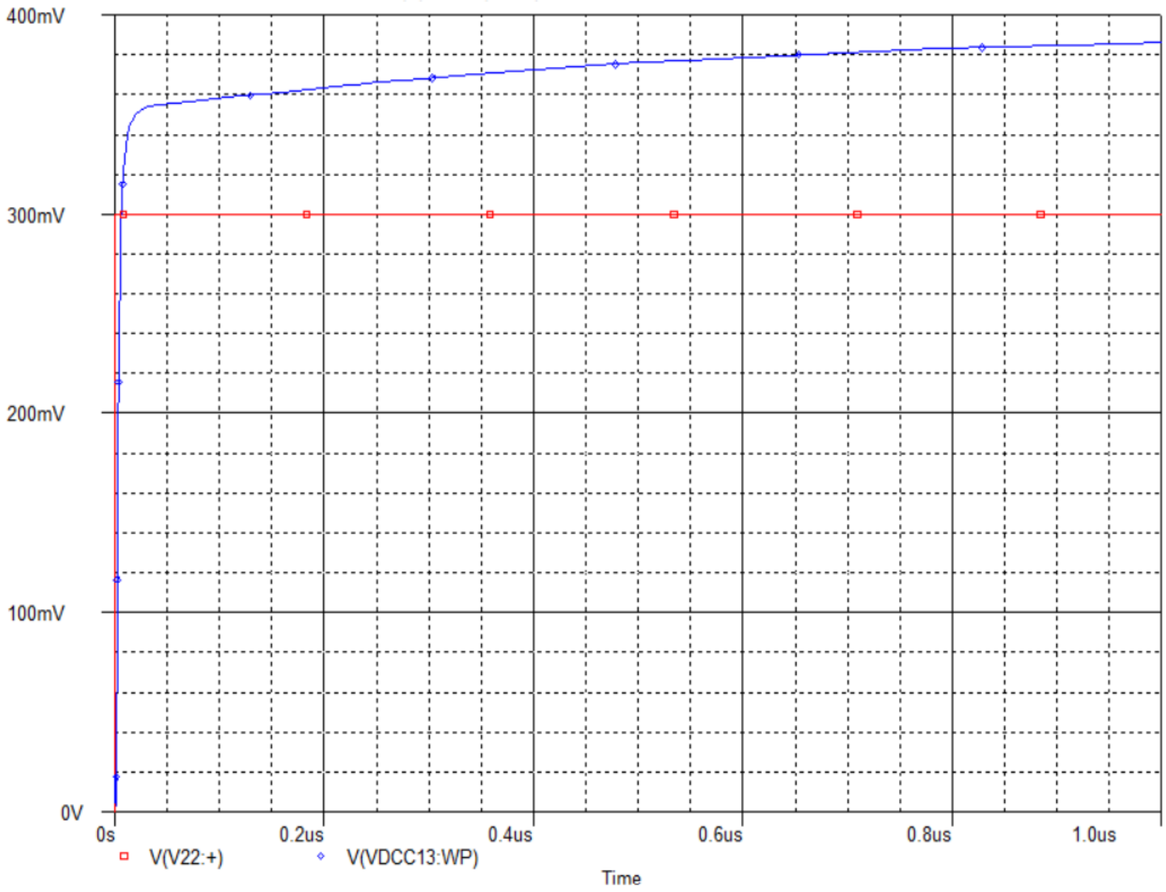

Fig.40 Step response of PI controller

5.4 Simulation of Proportional-Derivative or PD Controller

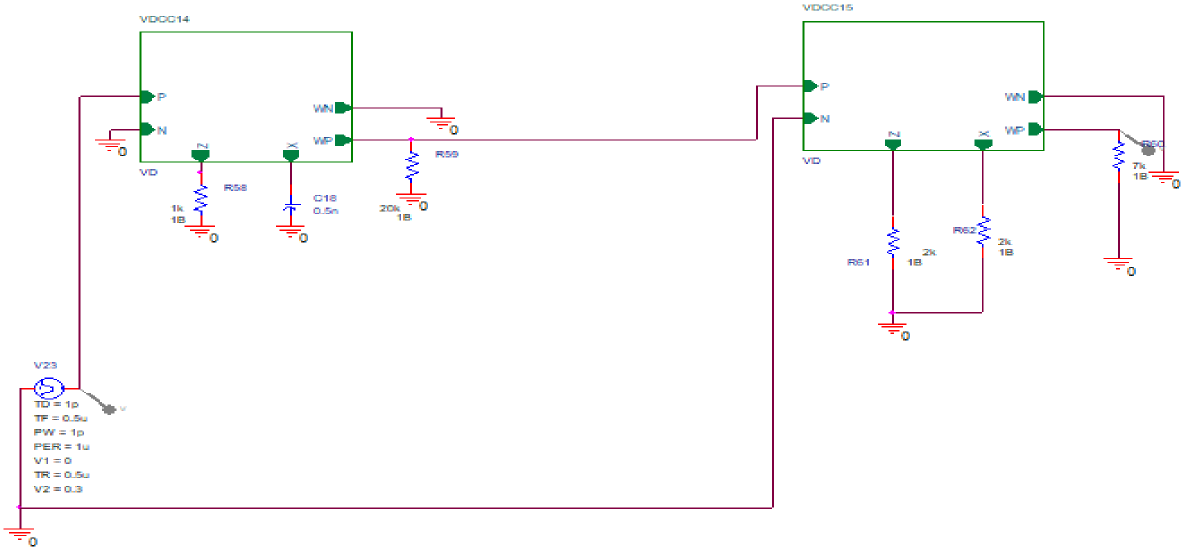

Fig.41 PD controller using VDCC block in PSPICE

The stimulated output of PD controller for a triangular input is shown in below figure with $K_P = 1.939$ and $K_D = 5.37 * 10^{-6}$ respectively.

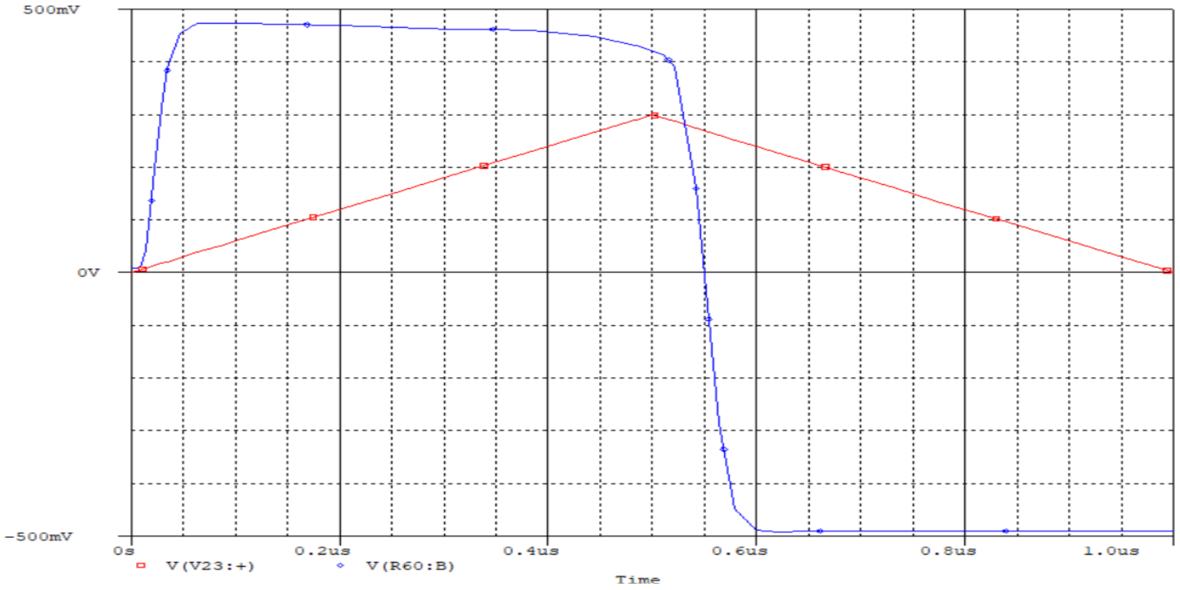

Fig.42 Response of PD controller for a triangular input

5.6 Simulation of Proportional-Integral-Derivative or PID Controller

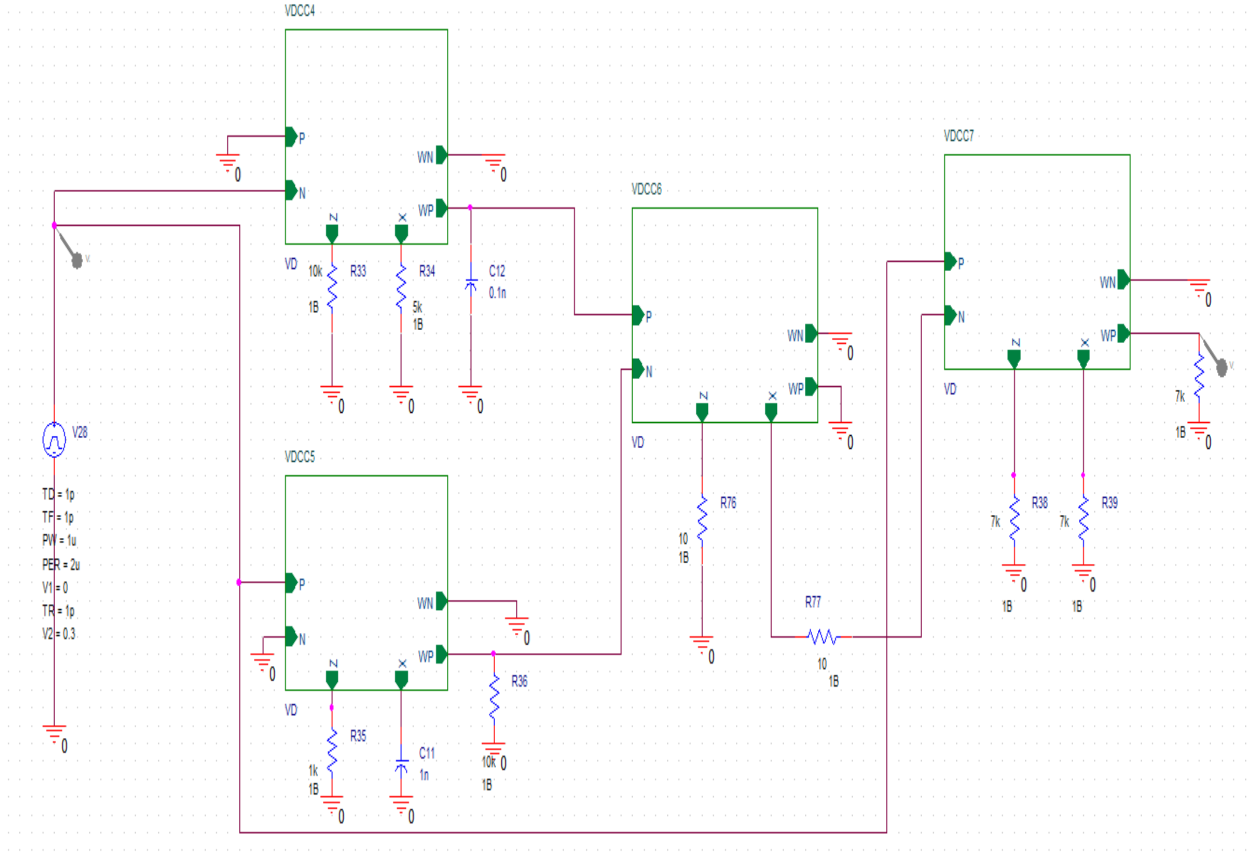

Fig.43 PID controller using VDCC block in PSPICE

The stimulated output of PID controller for a step input is shown in below figure with $K_P = 1.939$ and $K_I = 0.029 * 10^6$ $K_D = 14.87 * 10^{-9}$ respectively.

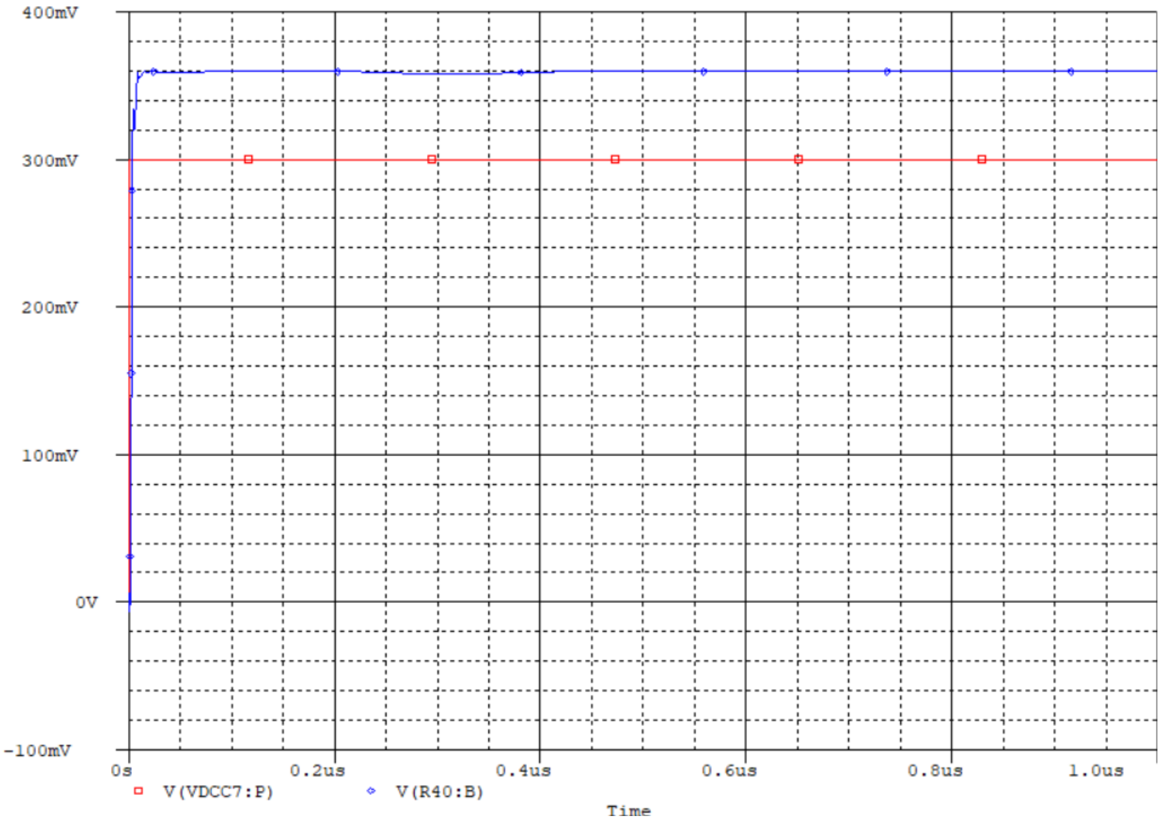

Fig.44 Response of PID controller for a step input

5.7 Simulation of Open loop Second order LPF filter using VDCC

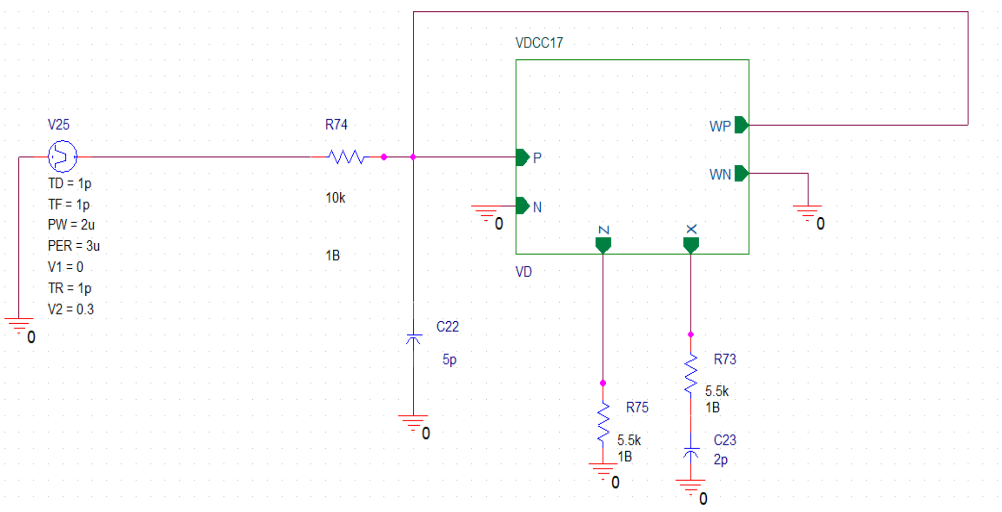

Fig.45 2^{nd} Order LPF filter using VDCC [36]

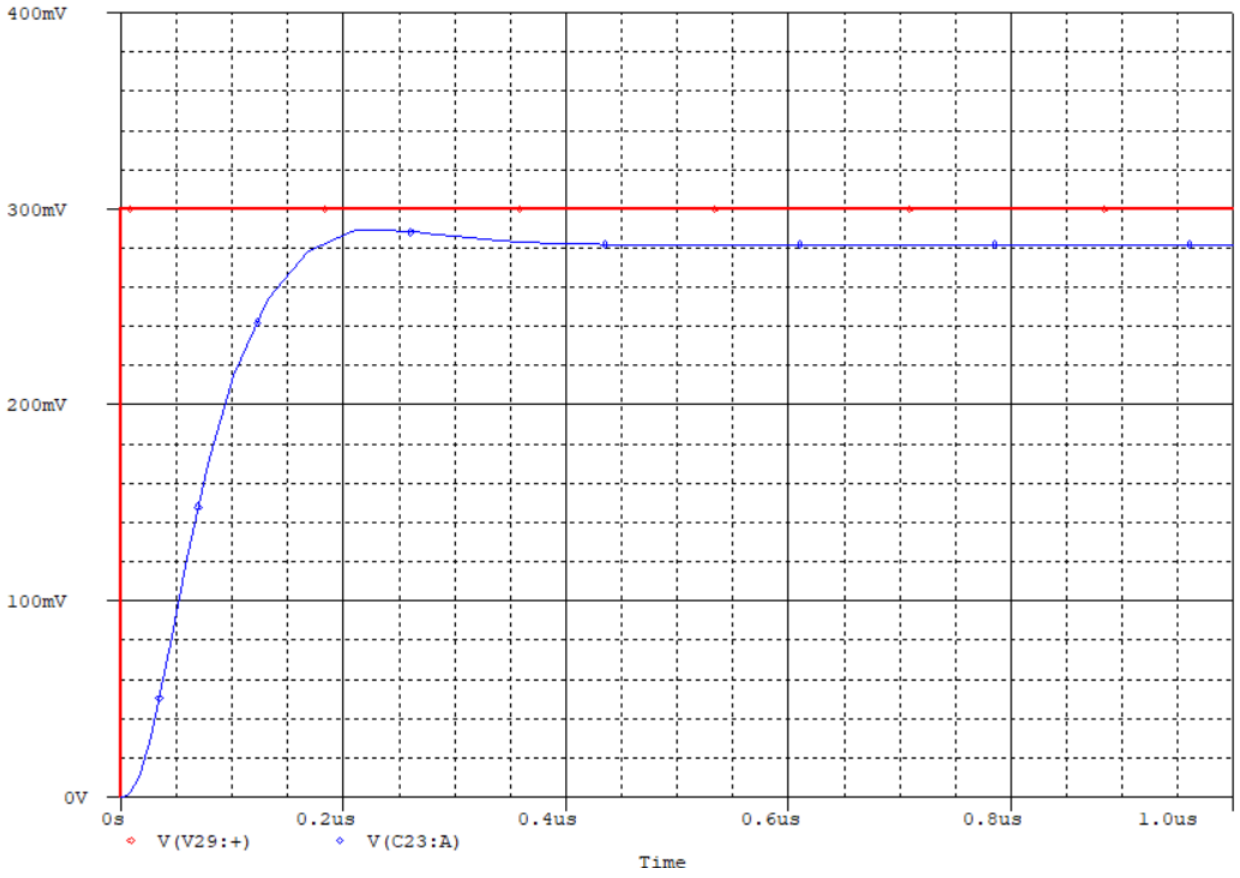

Fig.46 Open loop 2^{nd} Order LPF filter step response

5.8 Simulation of Closed loop Second order LPF filter using VDCC

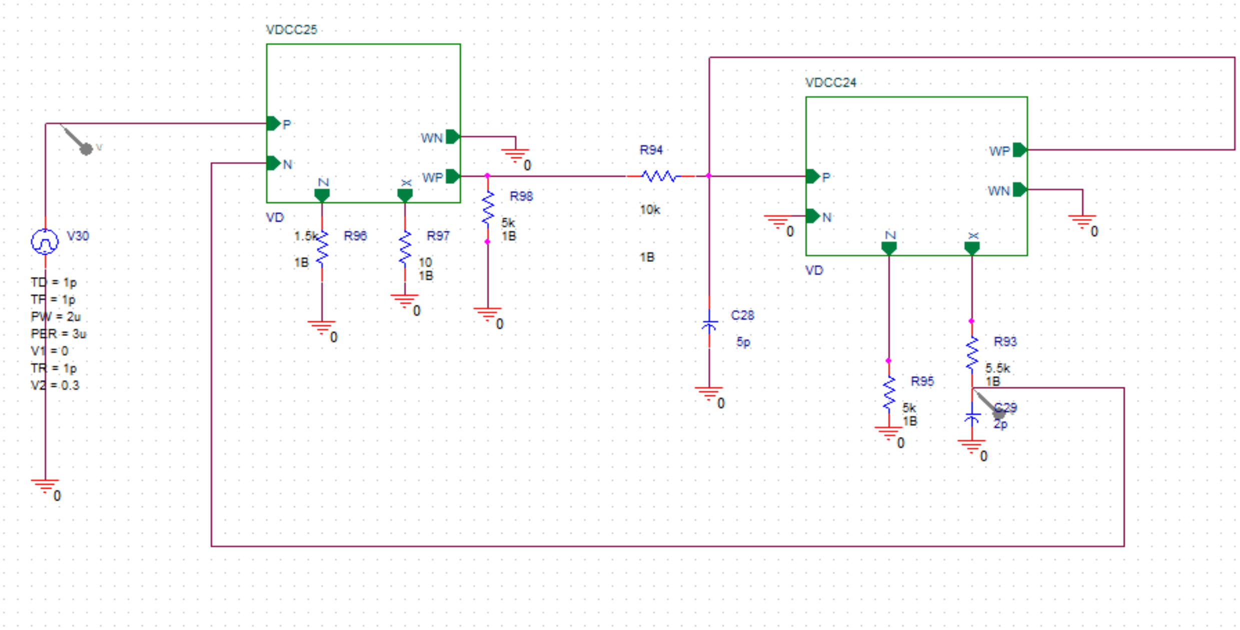

Fig.47 Closed loop 2^{nd} Order LPF filter

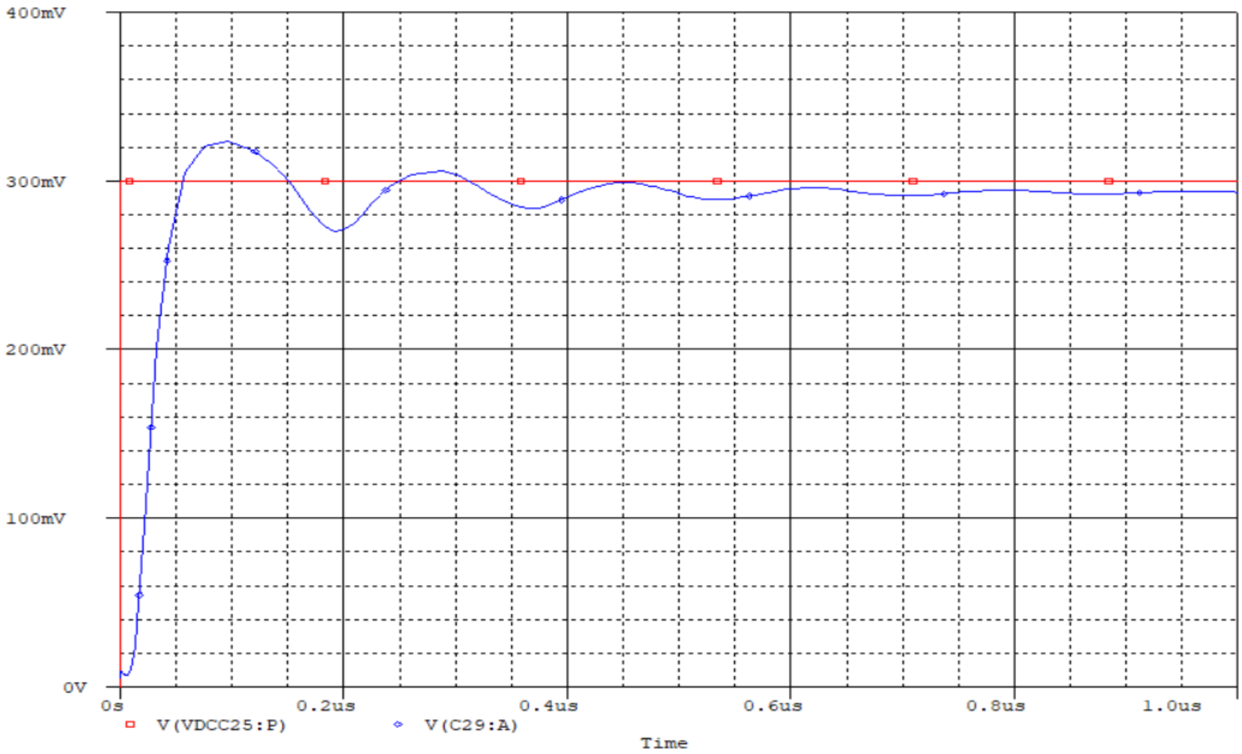

Fig.48 Step response of closed loop 2^{nd} Order LPF filter

5.9 Simulation of Closed loop Second order LPF filter with PID Controller

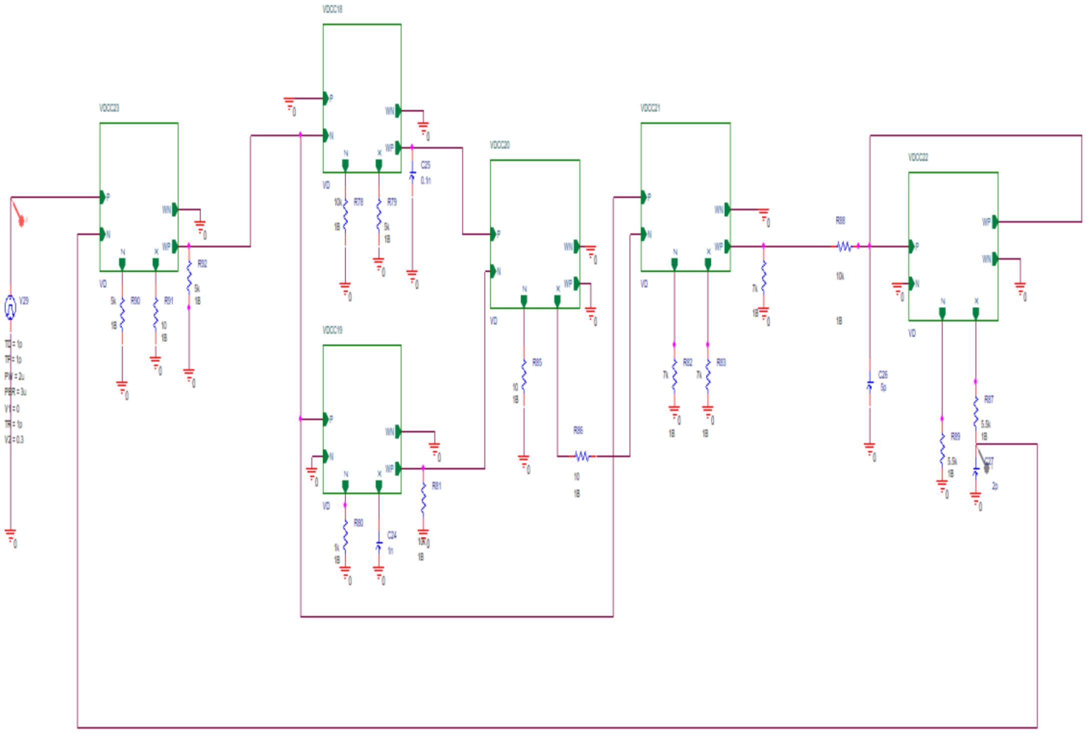

Fig.49 2^{nd} Order LPF filter with PID Controller

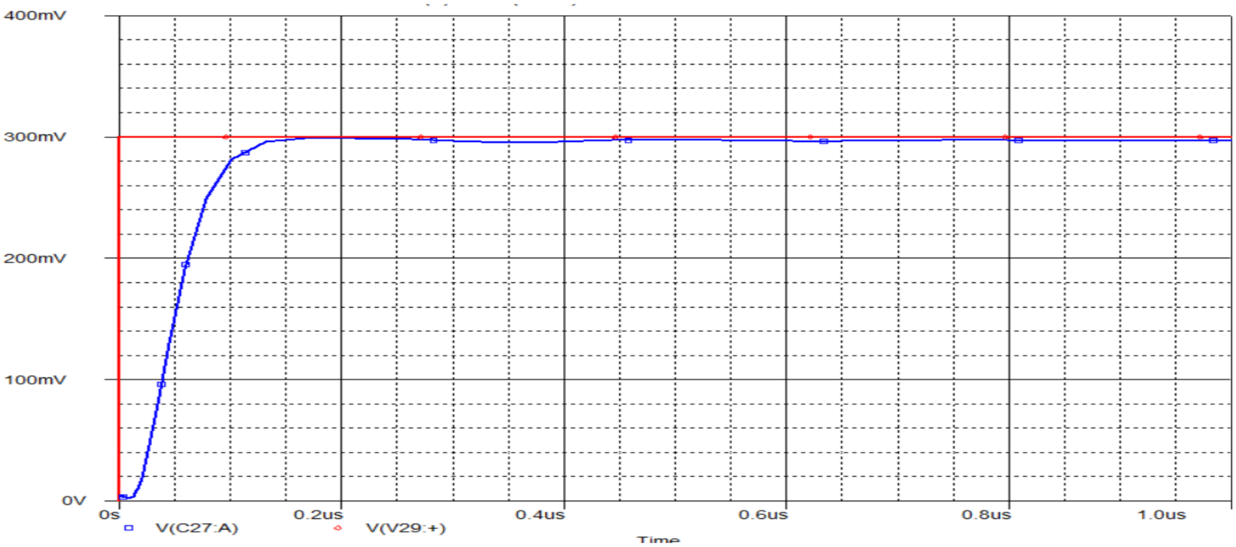

Fig.50 Step response of closed loop 2^{nd} Order LPF filter with PID controller

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

Active building block namely the VDCC is discussed in detail. The structure of VDCC using MOS Transistor is verified by simulating the structure with the help of PSPICE program. AC characteristics of input-output were verified using 0.18μm TSMC process parameters.

Further we presented Proposed PID controller using VDCC and its structure is verified by simulating each block of PID controller and also with closed loop system. From that we can conclude that the PID controller improved the every aspects of timing for a step input response.

The blocks of VDCC are tunable which gives an advantage over previously proposed controller and also the have the advantage of all grounded passive elements which can be convenient for IC implementation. This proposed PID controller using VDCC block design is more robust than the previous PID controller strategies, offering wider bandwidth, greater dynamic range and electronic tuning capabilities. It can tune the device gain without affecting the circuitry.

There is scope of improvement by scaling down the aspect ratio of MOS transistor. Also errors due to leakage or parasitic capacitance can be reduced using Compensation techniques. A lot of work can also be done in determining possible realizations of VDCC using other discrete and commercially available components like Operational Trans-conductance Amplifiers (OTA), Transistor arrays, CFOA etc. PID Controller can be used in closed loop system in series with lead/lag compensator in order to improve the system delay.

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