Current Backward Transconductance Amplifier and its Applications

A Dissertation submitted towards the partial fulfilment of
the requirement for the award of degree of

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Submitted by
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CERTIFICATE

This is to certify that the dissertation title "**Current Backward Transconductance Amplifier and its applications**" submitted by **G. Sai Vaibhav, Roll. No. 2K15/C&I/09**, in partial fulfilment for the award of degree of Master of Technology in "**Control and Instrumentation(C&I)",** run by Department of Electrical Engineering in Delhi Technological University during the year 2015-2017, is a bonafide record of student's own work carried out by him under my supervision and guidance in the academic session 2016-17. To the best of my belief and knowledge the matter embodied in dissertation has not been submitted for the award of any other degree or certificate in this or any other university or institute.

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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own work to the best of my belief and knowledge. I have fully cited all material by others which I have used in my work. It is being submitted for the degree of Master of Technology in Signal Processing & Digital Design at the Delhi Technological University. To the best of my belief and knowledge it has not been submitted before for any degree or examination in any other university.

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ABSTRACT

Emergence of various current mode analog building blocks is outcome of the considerable progress in analog signal processing. Ever since the introduction of current conveyors as basic building block in analog signal processing, many other active building blocks have been introduced so far. Current mode devices like current conveyor and current conveyor based active elements, seem to have a better closed loop bandwidth performance and signal dynamic range than conventional voltage amplifiers. CBTA is also the outcome of this advancements in the electronics domain. The prime concern is to provide better quality response, introduce versatility and modularity, and to develop circuits which could be better implemented in integrated circuit form. In this dissertation we presented bipolar implementation of CBTA. We realized various basic applications of CBTA like active filters, amplifier, inductor simulator. CBTA simulator inductors are further used in the realization of higher order filters by using replacement technique in LC ladder filters and general all pole technique.

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LIST OF ABBREVATIONS

CBTA	-	Current Backward Transconductance Amplifier
g_m	-	Transconductance gain
Z_{in}	-	Input impedance
μ	-	Voltage gain
α	-	Current gain
CDTA	-	Current Differencing Transconductance Amplifier
VDTA	-	Voltage Differencing Transconductance Amplifier
VDCC	-	Voltage Differencing Current Conveyor
VD-DIBA	-	Voltage Differencing Differential Input Buffered Amplifier
CDBA	-	Current Differencing Buffered Amplifier
VDBA	-	Voltage Differencing Buffered Amplifier
DVCFA	-	Differential Voltage Current Feedback Amplifier
DVCC	-	Differential Voltage Current Conveyor
CDCC	-	Current Differencing Current Conveyor
CFTA	-	Current Feedback Transconductance Amplifier
MO-CFTA	-	Multiple Output Current Feedback Transconductance Amplifier
CDDITA	-	Current Differencing Differential Input Transconductance Amplifier
CC	-	Current Conveyor
CFOA	-	Current Feedback Operational Amplifier
CC-CDBA	-	Current Controlled Current Differencing Buffered Amplifier
CC-CDTA	-	Current Controlled Current Differencing Transconductance Amplifier

CCTA	-	Current Conveyor Tranconductance Amplifier
FB-VDBA	-	Fully Balanced Voltage Differencing Buffered Amplifier
CFBTA	-	Current Follower Buffered Transconductance Amplifier
CIBTA	-	Current Inverter Buffered Transconductance Amplifier
I_{in}	-	Current source
V_{AC}	-	Voltage source
R_s	-	Source resistance
R_l	-	Load resistance
L	-	Inductor
R	-	Resistor
C	-	Capacitor
FI	-	Floating Inductor
GI	-	Grounded Inductor

Chapter 1
INTRODUCTION

1.1 Introduction

The present work deals with the active building block Current Backward Transcondcutance Amplifier(CBTA) and its basic applications like amplifiers, grounded and floating inductors and active filters in analog signal processing.

Major developments had taken place in the field of analog electronics and signal processing in the last quarter of twentieth century. Now a wide research is going to bring the new active devices into real world apart from some, which are there from the past like operational amplifiers, operational transconductance amplifier, current feedback operational amplifier etc. Signal processing is used in various applications like instrumentation, biomedical signal processing, communication systems and control systems etc., Signal processing can be done in two different ways

1) Discrete time method called as digital signal processing and
2) Continuous time method known as analog signal processing.

Analog signal processing has been used for now more than 6 to 7 decades and it uses passive components such as resistors, capacitors and active elements like transistors (BJTs, MOSFETs). With the advent of computers whose functioning is in digital domain, the other type of processing known as digital signal processing has also become popular in the present days. Analog signal processing is based on processing of signals in their natural form in analog system and so the solutions are obtained in real time domain whereas in digital signal processing the results may or may not give results in real time, as it depends on numerical calculations. At the same time, digital signal processing has two main advantages over analog approach. They are

1) Repeatability: The same signal reproduces the same results if it is processed multiple number of times whereas in analog systems the parameter variation like change in temperature may lead to change in the results.
2) Flexibility: In analog signal processing we need to design a system for each kind of operation while in digital approach same hardware can be used for various signal processing operations.

In addition to the above advantages digital signal processing has other advantages like better noise immunity, they are compact in size. As digital signals are encrypted only the intended receiver can decode it. It ensures safety to the information transmitted over long distances and it enables multi-directional transmission simultaneously.

But as all the signals in the nature are continuous in both time and amplitude, so analog circuits are essential in today's high performance and complex systems. Therefore analog circuits act as a bridge between the real world signals and digital systems. Apart from above factors advantage of analog systems is bandwidth compared to digital domain.

Operational amplifier became the basic building block used in analog signal processing after the advent of integrated circuits in analog circuit design. From that time various applications of analog circuits have evolved and the characteristics of the devices have changed a lot. There are various limitations of the operational amplifier circuits in the voltage mode(VM) of operation such as limited bandwidth at high closed-loop gains. This is because of the constant gain-bandwidth product of the device. The operational amplifier with the limited slew rate affects the signal in the high frequency range of operation.

The devices operating in the current mode of operation like current conveyors and active devices based on current conveyor, appear to have a better closed loop bandwidth and signal dynamic range than the general voltage amplifiers. Although the circuits operating in the current mode of operation and the related various active devices became an important circuits with the characteristics that make them to rival the devices operating in voltage mode of operation in the vast area of applications.

1.2 Voltage mode and current mode signal processing

Any signal processing in electronic circuits is performed by movement of charge and is characterised by variables like current or voltage. The circuit in which the input as well as the output variables are voltages is referred as voltage mode circuit. In the same way circuits in which the input as well as the output variables are current are generally called as current mode circuits. The main reason for using only voltages and currents is that active devices which are exploited in analog electronics operate mostly with resistance(conductance) as parameter for controlling the signal processing. The signal is processed by miscellaneous voltage-current and current-voltage conversions, amplification, weighted addition and multiplication etc. From the earlier times, voltage has been used as the main variable for signal processing because the thinking in terms of voltage is easier and simpler for the designers than in terms of currents. During the past few decades the analog electronics became practically only voltage mode processing and most of the building blocks used are typical voltage processing circuits.

In order to increase the speed of circuits for analog signal processing and to decrease the supply voltages of integrated circuits, designers focussed their attention on current mode of operation. The difference between voltage mode and current mode 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 current processing blocks cannot be arranged in serial manner. 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.

Since the work carried out in this dissertation deals with active building blocks of recent origin, it is worthwhile to present the characteristics of some of the recent active building block in the following. This summary does not include current conveyors and other derivatives of current conveyors.

1.3 Various active building blocks

1.3.1 Current differencing buffered amplifier(CDBA)

The circuit symbol of the current differencing buffered amplifier (CDBA) is shown in Figure 1.1, where p and n are input terminals, w and z are output terminals.

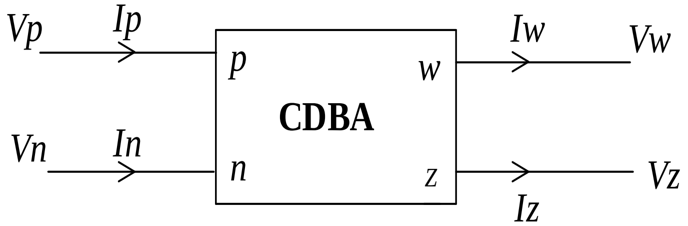


Fig 1.1 Symbol of CDBA[1]

CDBA is characterized by the matrix given below:

$$\begin{bmatrix} I_z \\ V_w \\ V_p \\ V_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ i_w \\ i_p \\ i_n \end{bmatrix}$$

An exemplary CMOS implementation of the device as per the matrix is given as under

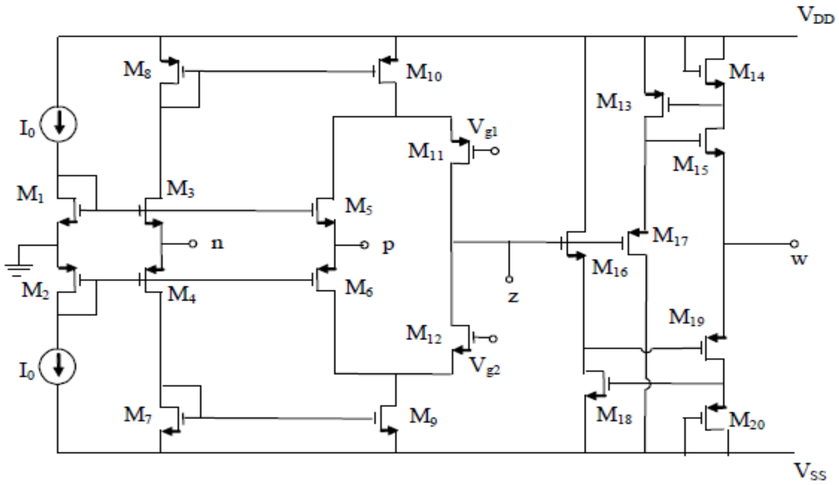


Fig 1.2 CMOS implementation of CDBA[1]

1.3.2 CURRENT DIFFERENCING TRANSCONDUCTANCE AMPLIFIER, CDTA[2]

A new active element with two current inputs and two kinds of current output, namely the Current- Differencing Transconductance Amplifier (CDTA) was proposed by Dalibor Biolek [2] and the element is a synthesis of the known CDBA (Current-Differencing Buffered Amplifier) and OTA (Operational Transconductance Amplifier) elements to facilitate the realization of current-mode analog filters.

Behavioural model of this device is given in Fig 1.3 like CDBA, it has two current inputs *p* and *n*. Their difference flows from from terminal *z*. The voltage across the *z* terminal is transferred by a transconductance *g* to a current that is taken out as a current pair to the *x* terminals.

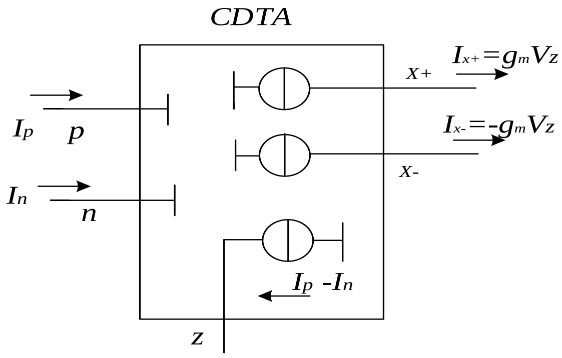
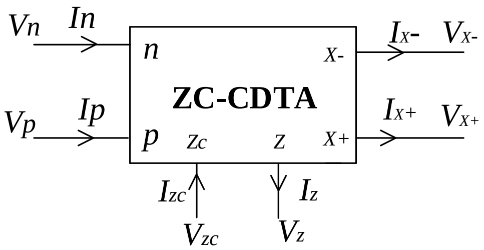


Fig 1.3 Behavioural model of CDTA

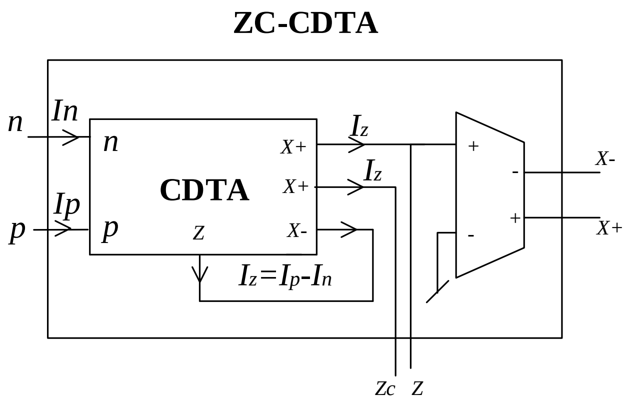
1.3.3 ZC-CDTA

Like CDTA, this device provides a pair of complementary terminals whose currents are equal in magnitude, but flow in opposite directions, and the product of transconductance (gm) and voltage at the z-terminal determines their magnitudes. The circuit equations of the ZC-CDTA are as follows

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_{zc} \\ I_{x+} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & g_m & 0 & 0 & 0 \\ 0 & 0 & -g_m & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_z \\ V_{zc} \\ V_{x+} \\ V_{x-} \end{bmatrix}$$



(a)



(b)

Fig 1.4 (a) Symbol of ZC-CDTA (b) ZC-CDTA implementation based on CDTA and OTA

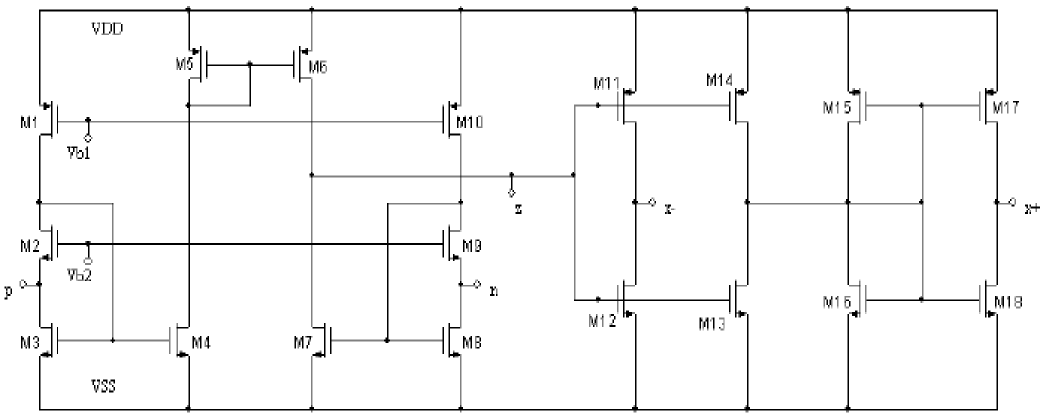


Fig 1.5 CMOS realization of CDTA

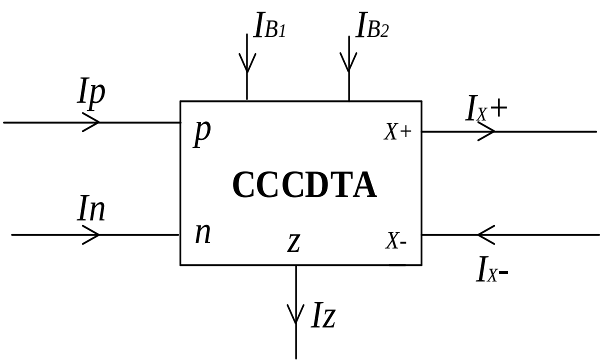
1.3.4 CURRENT CONTROLLED CDTA

Current differencing transconductance amplifier (CDTA) is a versatile device which may be used in the realization of a class of analog signal processing circuit; especially analog frequency filters. It is really current-mode element whose input and output signals are currents. In addition, output current of CDTA can be electronically adjusted.

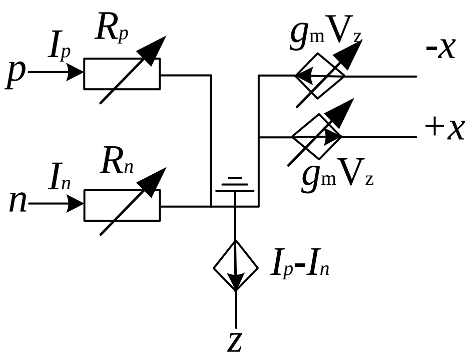
The schematic symbol and the ideal behavioral model of the CCCDTA are shown in Fig**.** 1.6(a) and (b).

The characteristics of the ideal CCCDTA are represented by the following hybrid matrix

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} R_p & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \end{bmatrix}$$



(a)



(b)

Fig 1.6 (a) symbol (b) Equivalent Circuit of CCCDTA

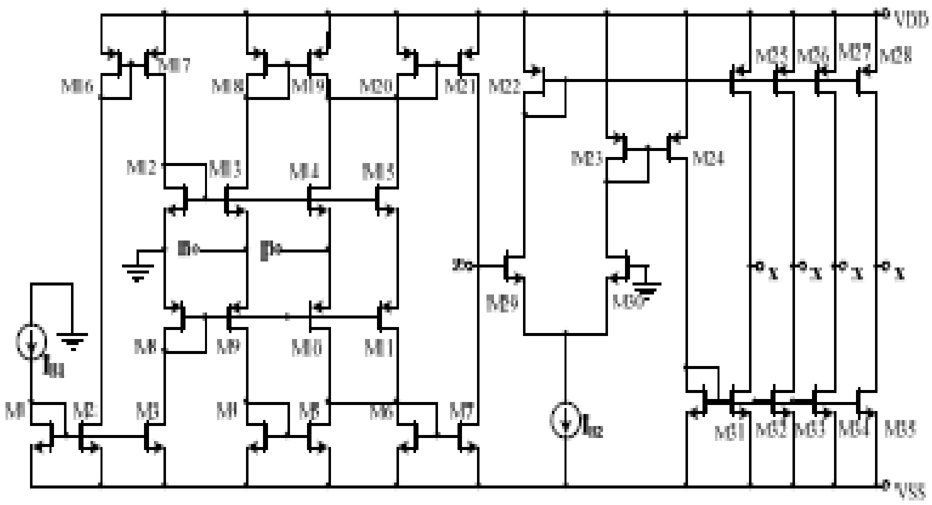


Fig 1.7 Schematic of the CMOS CCCDTA.

1.3.5 CURRENT CONVEYOR TRANSCONDUCTANCE AMPLIFIER, CCTA

The CCTA (Current Conveyor Transconductance Amplifier) was proposed by Roman Prokop**,** Vladislav Musil in 2005 [3]. Behavioral model of the CCTA is shown in Fig. 1.8. From its behavior the possible internal structure can be visible (Fig. 1.9). The CCTA consists from two basic blocks. The input is represented by the current conveyor CCIII that is followed by double output transconductance opamp (OTA).

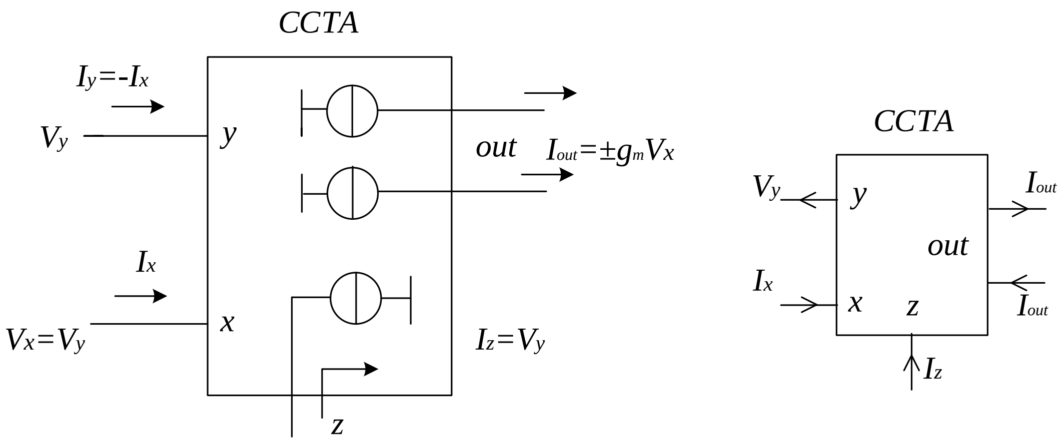


Figure 1.8 (a) Behavioral model of CCTA, (b) example of schematic symbol of CCTA

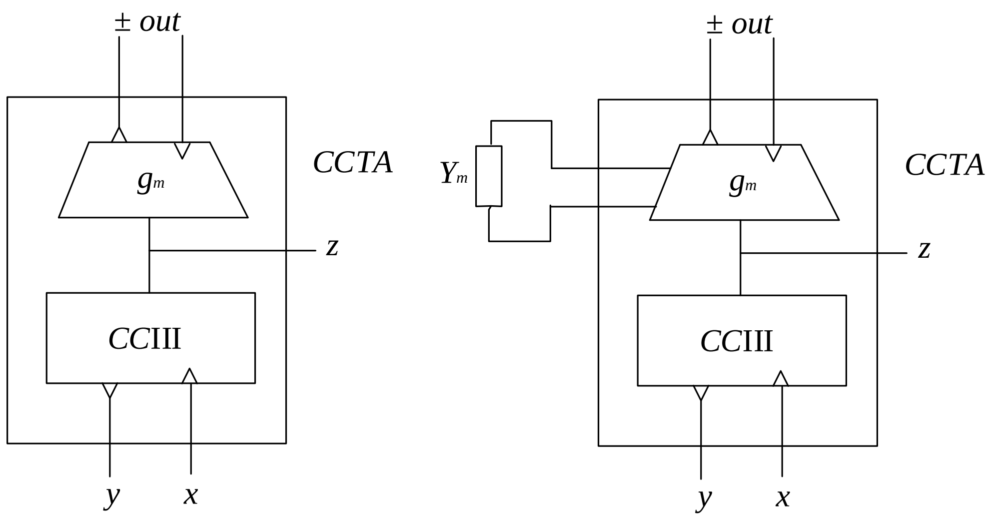


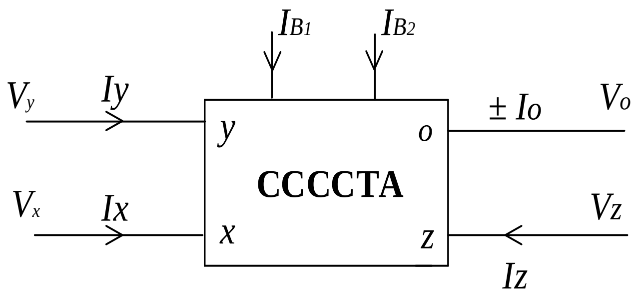
Figure 1.9 (a) CCTA element as a connection of CCIII and OTA element

(b) CCTA with possibility to choose "transconductance" by an outside two-pole

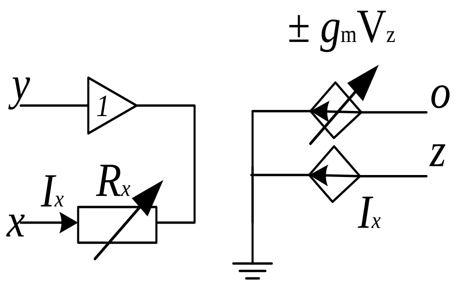
1.3.6 CURRENT CONTROLLED CCTA, CC-CCTA

A modified-version of CCTA, which is named current controlled current conveyor transconductance amplifier (CCCCTA) was proposed by Montree Siripruchyanun and Winai Jaikla [11] in its basic structure it is a four terminal device whose symbolic representation, behavioural model and port relations are given below.

BASIC CONCEPT OF CCCCTA



(a)



(b)

Fig 1.10 The CCCCTA (a) symbol (b) equivalent circuit

CCCCTA properties are similar to the conventional CCTA, except that the CCCCTA has finite input resistance *Rx* at the *x* input terminal. This parasitic resistance can be controlled by the bias current I_{B1} as shown in the following equation

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_y \\ V_y \\ V_z \\ V_o \end{bmatrix}$$

Where

$$R_x = \frac{V_T}{2I_m} \ , g_m = \frac{I_{B2}}{2V_T}$$

where g_m is the transconductance gain of the CCCCTA and V_T is the thermal voltage. An exemplary implementation of this device using bipolar technology is given in Fig 1.11[11]

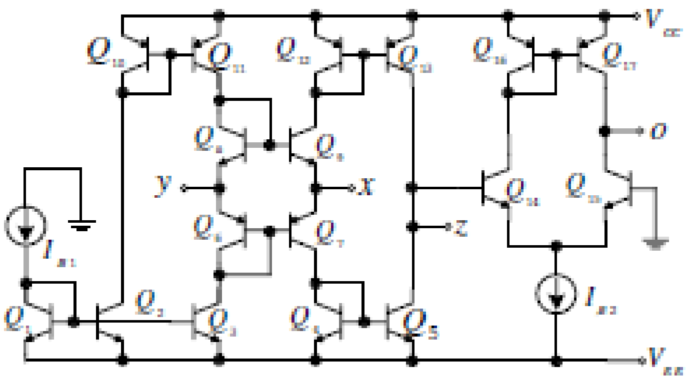


Fig 1.11   Realisation of CCCCTA using Bipolar technology

1.3.7 MO-CCCCTA

The MO-CCCCTA properties can be described in the following matrix equation

$$\begin{bmatrix} I_y \\ V_x \\ I_{z\pm} \\ I_{o\pm} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}$$

The MO-CCCCTA has a finite input resistance R_X at the X input terminal and an additional transconductance g_m amplifier in the output side. The parasitic resistance R_X and the transconductance g_m can be controlled by bias currents I_{b1} and I_{b2}, respectively. A BJT based MO-CCCCTA is given in [4]. The intrinsic resistance (R_X) and transconductance (g_m) are expressed as

$$R_x = \frac{V_T}{2I_{b1}} \;, g_m = \frac{I_{b2}}{2V_T}$$

where I_{bi} (i = 1, 2) and V_T are the bias currents and the thermal voltage, respectively.

MO-CCCCTA

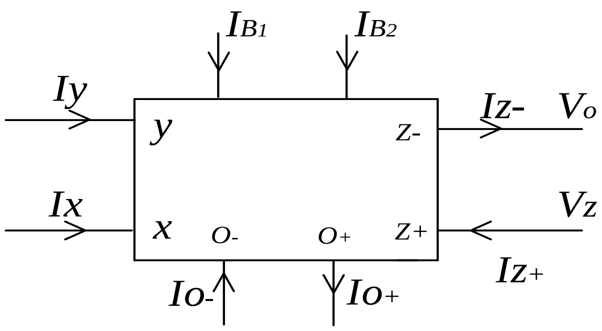


Fig 1.12 Functional symbol of MO-CCCCTA

CMOS implementation of the active block is shown in figure 1.13,

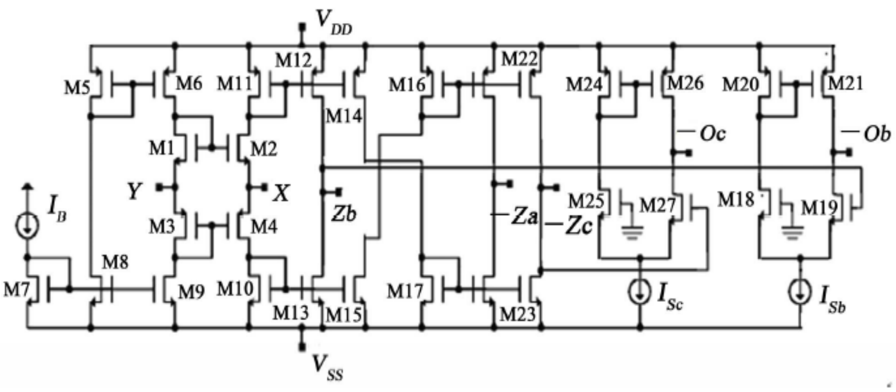


Fig 1.13 CMOS implementation of MO-CCCCTA

1.3.8 DIFFERENTIAL VOLTAGE CCTA, DVCCTA

CIRCUIT DESCRIPTION

The DVCCTA is based on DVCC [13] and consists of differential amplifier as input, current mirrors and transconductance amplifier. The port relationships of the proposed DVCCTA as shown in Fig. 1.14 can be characterized by the following matrix:

$$\begin{bmatrix} I_{y1} \\ I_{y2} \\ V_x \\ I_{z+} \\ I_{z-} \\ I_{o-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -g_m & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{y1} \\ V_{y2} \\ I_x \\ V_{z+} \\ V_{z-} \\ V_{o-} \end{bmatrix}$$

where g_m is transconductance of the DVCCTA

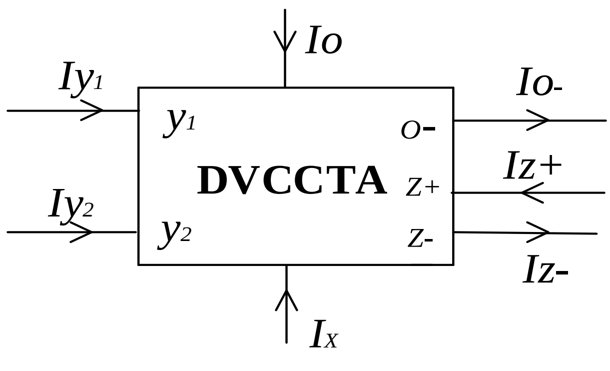


Fig 1.14 Circuit symbol of DVCCTA

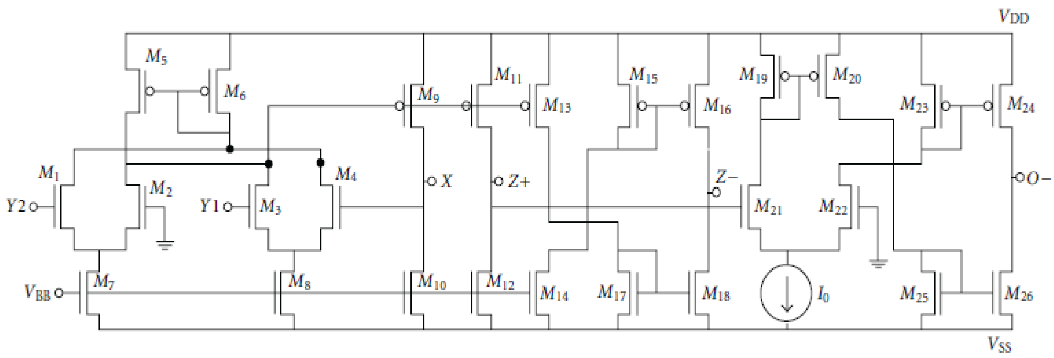


Fig 1.15 CMOS model of VDCCTA

1.3.9 DIFFERENTIAL DIFFERENCE CCTA, DDCCTA

The DDCCTA element is based on the use of the DDCC as an input stage and the OTA as an output stage. The DDCCTA can easily be implemented from a DVCCTA by adding the Y3 terminal as shown in Fig. 1.16, the port relations of the DDCCTA are given below

$$i_{Y1} = i_{Y2} = i_{Y3} = 0,\ v_X = v_{Y1} - v_{Y2} + v_{Y3},$$

$$i_Z = i_X,\ i_O = g_m v_Z$$

where g_m is the transconductance parameter of the DDCCTA.

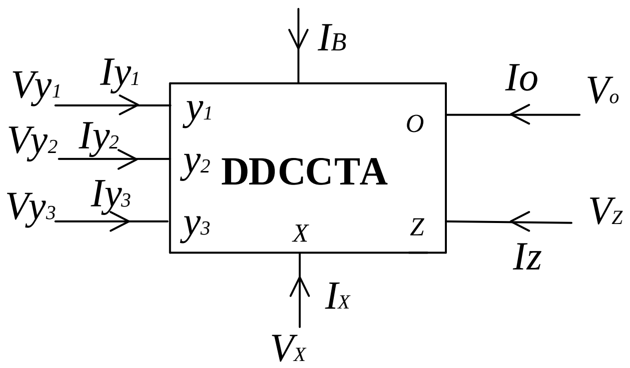


Fig 1.16 Circuit symbol of DDCCTA

1.3.10 VOLTAGE DIFFERENCING TRANSCONDUCTANCE AMPLIFIER, VDTA

The circuit symbol of the active element, VDTA, is shown in Fig. 1.17, where V_P and V_N are input terminals and Z, X+ and X- are output terminals. All terminals exhibit high impedance values.

The characteristics of the VDTA are represented by the following matrix

$$\begin{bmatrix} I_z \\ I_{x-} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_{VP} \\ V_{VN} \\ V_Z \end{bmatrix}$$

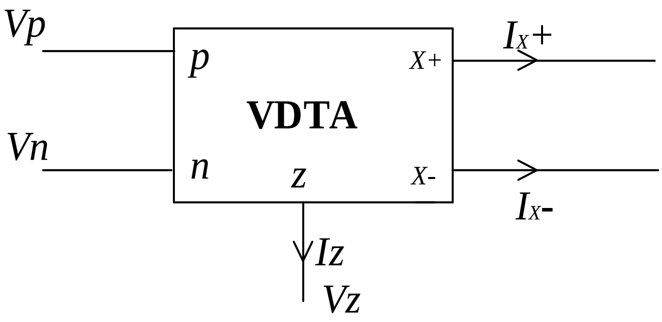


Fig 1.17 Circuit symbol of VDTA

Consequently, the above describing-equations, the input stage and output stage can be simply implemented by floating current sources. According to input terminals, an output current at Z terminal is generated. The intermediate voltage of Z terminal is converted to output currents. The new CMOS realization of the VDTA is shown in Fig. 1.18.

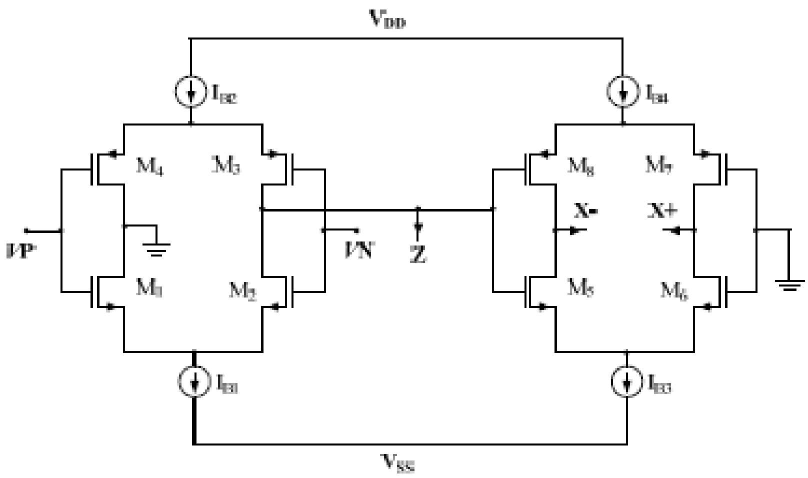
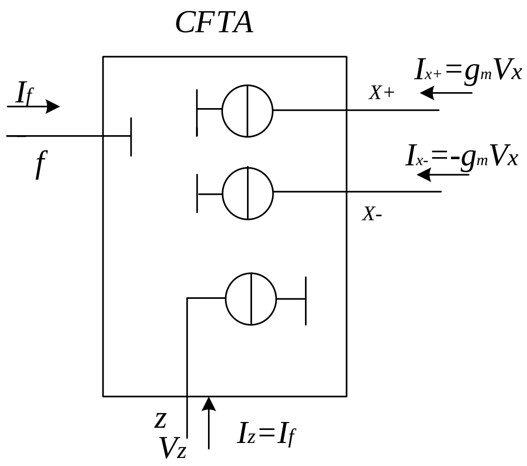


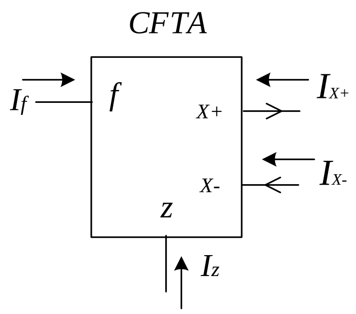
Fig 1.18 CMOS implementation of VDTA

1.3.11 CURRENT FOLLOWER TRANSCONDUCTANCE AMPLIFIER, CFTA

This active element was introduced by Norbert Herencsar, Jaroslav Koton, Kamil Vrba, and Ivo Lattenberg in 2008 [5]. The ideal behavioural model of the CFTA element is shown in Fig. 1.19(a). The element is a combination of the Current Follower (CF), which is the input part of the designed element, and the Balanced Output Transconductance Amplifier (BOTA) [6,7], which forms the output part of the element. The schematic symbol of the CFTA element is shown in Fig. 1.19(b)



(a)



(b)

Fig 1.19 (a) Behavioral model of CFTA element (b) Schematic symbol of CFTA

The element has one low impedance current input *f*. Current from the terminal *f* is transferred by the Current Follower to auxiliary terminal *z*. The voltage V_z on this terminal is transformed into current using the transconductance *g*m, which flows into output terminals *x*+ and *x*-.

The terminal relations are represented by the following matrix:

$$\begin{bmatrix} I_z \\ I_{x+} \\ I_{x-} \\ V_f \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ g_m & 0 & 0 & 0 \\ -g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_z \\ V_{x+} \\ V_{x-} \\ I_f \end{bmatrix}$$

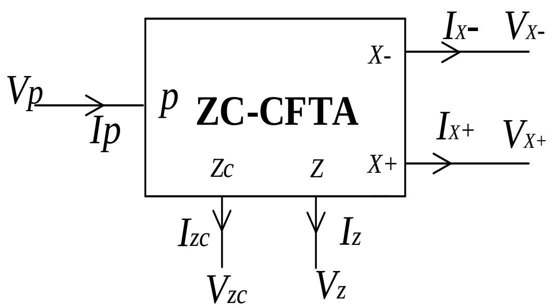
1.3.12 Z-COPY CFTA, (ZC-CFTA)

Z-copy current follower transconductance amplifier (ZC-CFTA) was firstly suggested in [8]. The ZC-CFTA is slightly modified from the conventional CDTA by replacing the current differencing unit with a current follower and complementing the circuit with a simple current mirror for copying the z-terminal current. Thus, the ZC-CFTA element can be thought of as a combination of the current follower, the current mirror and the multi-output operational transconductance amplifier. The symbolic notation and equivalent of the ZCCFTA are shown in Fig. 1.20. The ZC-CFTA element consists of low-impedance input p, high-impedance outputs z, zc, x and x+. The input current from the terminal p (i_p) is respectively transferred to the terminal z (i_z) and auxiliary terminal zc (i_{zc}) by a current follower and a current mirror. The voltage drop at the terminal z (v_z) is transformed into output currents via a multi-output transconductance stage with a transconductance gain (g_m). Using standard notation, the port relations of the ZC-CFTA can be defined by the following matrix equation [9].

$$\begin{bmatrix} v_p \\ i_z \\ i_{zc} \\ i_{x+} \\ i_{x-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & +g_m & 0 & 0 & 0 \\ 0 & -g_m & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_p \\ v_z \\ v_{zc} \\ v_{x+} \\ v_{x-} \end{bmatrix}$$

where $+g_m$ and and $-g_m$ correspond for the positive output current (i_{x+}) and negative output current (i_{x-}), respectively.

In general, the g_m-value is electronically controllable by external bias current/voltage.



(a)

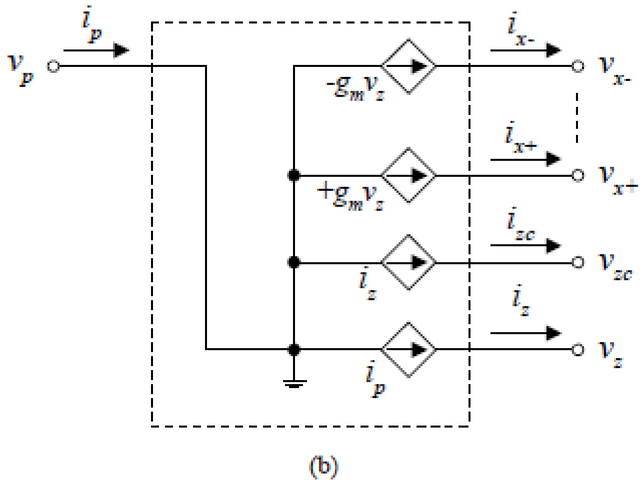


Fig 1.20 (a) Electrical Symbol (b) Equivalent circuit of ZC-CFTA

1.3.13 VOLTAGE DIFFERENCING BUFFERED AMPLIFIER ,VDBA

In [8], the circuit principle called VDBA (Voltage Differencing Buffered Amplifier) is proposed as an alternative to the existing CDBA (Current Differencing Buffered Amplifier) [1]. The input stage of VDBA is composed of the differential-input OTA. The voltage buffer is connected to the OTA current output. This structure is semi-differential.

CIRCUIT DESCRIPTION

The proposed schematic symbol and behavioral model of the FB-VDBA are in Fig. 1.21 (a) and (b). The model can be described by the following set of circuit equations:

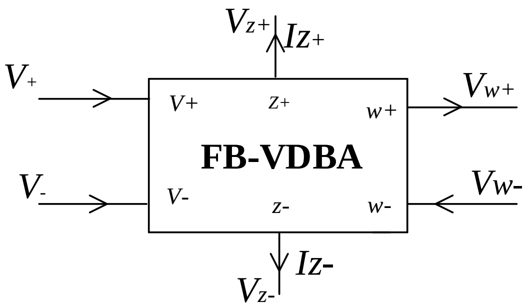
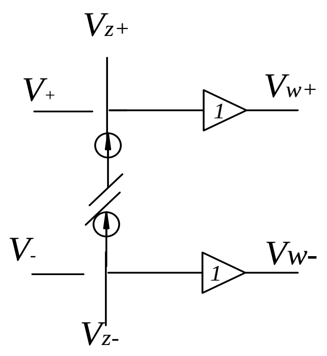


Fig. 1.21 (a) schematic symbol



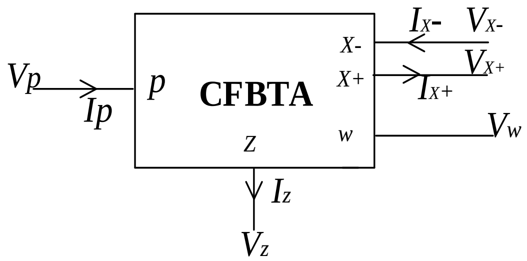
(b) behavioural model of VDBA

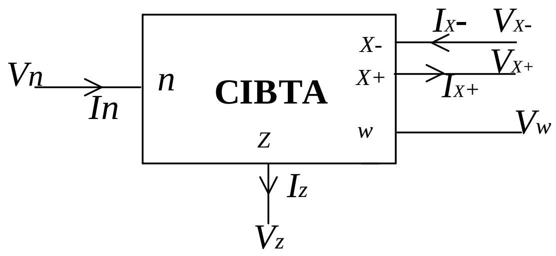
$$\begin{bmatrix} I_{z+} \\ I_{z-} \\ V_{w+} \\ V_{w-} \end{bmatrix} = \begin{bmatrix} g_m & -g_m & 0 & 0 \\ -g_m & g_m & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_+ \\ V_- \\ V_{z+} \\ V_{z-} \end{bmatrix}$$

FB-VDBA has a pair of high-impedance voltage inputs *v+* and *v-*, a pair of high-impedance current outputs *z+* and *z-*, and two low impedance voltage outputs *w+* and *w-*. The input stage can be simply implemented by a differential-input differential output OTA. When connecting two identical grounded resistors to the *z+* and *z-* terminals, the voltage drops on them will be of equal value but different directions. The output voltages of *w+* and *w-* terminals thus will be *Vw-* = *-Vw+*. In this way, the voltage inversion is achieved without the utilization of voltage inverter.

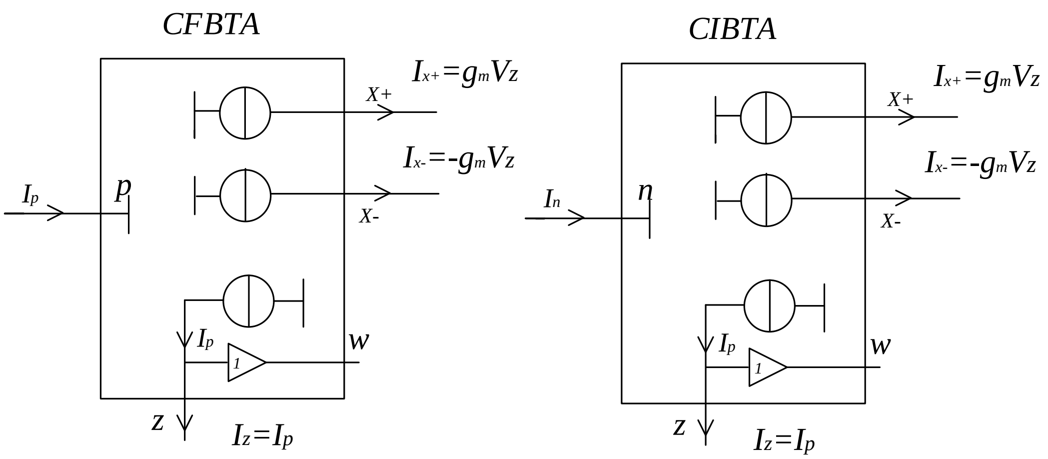
1.3.14 CURRENT FOLLOWER/INVERTER BUFFERED TRANSCONDUCTANCE AMPLIFIER (CFBTA, CIBTA)

The symbols and behavioral models of proposed active elements are in Fig. 1.22 (a) and (b). The corresponding circuit equations can be arranged in the following matrix form:





(a)



(b)

Fig. 1.22 (a) Symbol (b) Equivalent circuits of CFBTA and CIBTA

$$\begin{bmatrix} I_z \\ V_w \\ I_x \\ V_{p(n)} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & (-)1 \\ 1 & 0 & 0 & 0 \\ g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ I_w \\ V_x \\ I_{p(n)} \end{bmatrix}$$

According to the above Equations and equivalent circuits, the *p* and *n* input terminals behave as grounded because their voltages are zero. The *z*-terminal current is a copy of the *p* or *n* terminal current, flowing out of the device for CFBTA and into the device for CIBTA. Moreover, the *z* terminal voltage is copied to the low–impedance *w* terminal and transferred to the *x* terminal currents via the OTA transconductance *gm*.

CFBTA and CIBTA, represent two main improvements in comparison to the well–known CDBA and CDTA: 1) simplified input stage in the form of current follower or inverter, and 2) more universal output stage, containing both the multiple–output OTA for providing current outputs and the voltage buffer for supplying subsequent blocks with voltage–type signal.

After presenting a brief review of some of the recently proposed active building blocks in the following table we now present the terminal devices in terms of nature of the input/output quantities, their impedance level and their structure whether single ended or differentially.

S.No	Active element	Input		Impedance		Output
1	VDBA	Voltage	Differential	High	Low(W), High(Z)	Current(Z), Voltage (W)
2	VDTA	Voltage	Differential	High	High	Current
3	VDCC	Voltage	Differential	High	High	Current, Voltage
4	DVCFA	Voltage	Differential	High	Low(V), High(Z)	Current, Voltage
5	DVCC	Voltage	Differential	High	High	Current
6	CDTA	Current	Differential	Low	High	Current
7	CDCC	Current	Differential	Low	Low(X), High(Z, W)	Voltage(X), Current(Z,W)
8	MO-CFTA	Current	Single	Low	High	Current
9	MO-CITA	Current	Single	Low	High	Current

10	CDDITA	Current	Differential	Low	High (I_X^+, I_X^-), Low(Z,V)	Current, Voltage
11	CDBA	Current	Differential	Low	High, Low	Current, Voltage
12	CC-CDBA	Current	Differential	Finite	High, Low	Current, Voltage
13	CC-CDTA	Current	Differential	Finite	High	Current
14	CCTA	Current	Single	Low	High, Low	Current, Voltage
15	FB-VDBA	Voltage	Differential	High	High, Low	Current, Voltage
16	CFBTA/ CIBTA	Current	Single	Low	High, Low	Current, Low

1.4 Objectives of the project

In the present work we have selected an active building block namely CBTA(Current Backward Transconductance Amplifier) which was introduced in[1] and has not been used widely for signal processing application we have presented

1) A bipolar implementation the current backward transconductance amplifier(CBTA) using BJT of bipolar arrays NR100N(npn) and PR100N(pnp) and given its DC and AC characteristics.
2) Grounded inductor and floating inductor using the CBTA.
3) Active filters using the active element CBTA.

4) Higher order filter design using CBTA.

1.5 Organisation of thesis

Chapter 1: This chapter includes the general introduction about the project and the advantages of current mode devices over voltage mode devices. This chapter gives brief description and comparison between analog signal processing and digital signal processing. In this we presented how passive filters were developed initially and then later the development of active filters. It also contains the objectives of the project and the organisation of the thesis.

Chapter 2: This chapter presents the introduction of CBTA. This includes the various characteristics of CBTA like voltage transfer characteristic, current transfer characteristic and transfer conductance characteristic. In this chapter we presented the basic applications of CBTA like inverting amplifier, non-inverting amplifier. In this we also presented the first order active filters using CBTA.

Chapter 3: This chapter deals with the realisation of grounded inductor and floating inductor using CBTA. This chapter gives brief description of inductor simulators realized using various active devices so far. The realised inductor using CBTA is simulated using PSPICE simulation software. The grounded and floating inductor thus implemented will be further used in the 2^{nd} order RLC filter.

Chapter 4: The inductors realized in the chapter 3 is used in this chapter to realize high order LC ladder filters. Advantage of LC ladder filters is that they are lossless. The various filters realised in this chapter are 5^{th}low pass filter, 5^{th}high pass filter.

Chapter 5: In this chapter we presented the summary of the project and we also mentioned about the future scope in this area.

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Chapter 2

Current Backward Transconductance Amplifier

2.1 Introduction:

In the previous chapter we had presented a brief review of some of the important voltage mode and current mode active building blocks which are of recent origin and are being used extensively to develop different types of signal processing applications. In this chapter we describe an active building block Current Backward Transconductance Amplifier (CBTA) introduced in[1]. It is a five terminal active building block and from the literature review it appears that it has not attracted the attention of researchers working in the area of analog circuit design for its potential applications. In the following we describe the generic architecture of this block as given in [1]. We have simulated a bipolar implementation of CBTA in PSPICE and presented its DC as well as AC characteristics along with some exemplary applications in this chapter.

CBTA is a five terminal device out of which two terminals are inputs and three terminals are outputs. In the circuit symbol shown in the figure 1 p, n are input terminals and z^{+}, z^{-} , w, are output terminals.

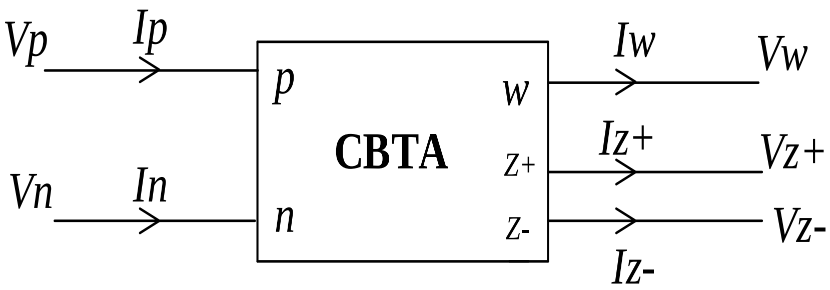

Fig 2.1 Symbol of the CBTA element [1]

The equivalent circuit of CBTA is shown in the figure 2.1 It has four terminals. The equivalent circuit has dependent current sources and dependent voltage sources. It has equivalent current sources at terminals p, n, z^{+}, z^{-} and dependent voltage source at terminal w. The input impedances for the ideal CBTA are infinite at p, n terminals. At z^{+}, z^{-} output terminals the impedances of an ideal CBTA are infinite where as the impedance at the terminal w is zero. The CBTA terminal equations can be defined as

$$I_{Z^+} = g_m(s)(V_p - V_n)$$

$$I_{Z^-} = g_m(s)(V_n - V_p)$$

$$V_W = \mu_w(s)V_{Z^+}$$

$$I_p = \alpha_p(s)I_w$$

$$I_n = -\alpha_n(s)I_w$$

$$\begin{bmatrix} i_{z^+} \\ i_{z^-} \\ v_w \\ i_p \\ i_n \end{bmatrix} = \begin{bmatrix} g_m & -g_m & 0 & 0 & 0 \\ -g_m & g_m & 0 & 0 & 0 \\ 0 & 0 & \mu_w & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_p \\ 0 & 0 & 0 & 0 & \alpha_n \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ v_{z^+} \\ v_{z^-} \\ i_w \end{bmatrix}$$

Where g_m - transconductance gain of CBTA

α_p - current gain of CBTA

α_n - current gain of CBTA

μ_w - voltage gain of CBTA

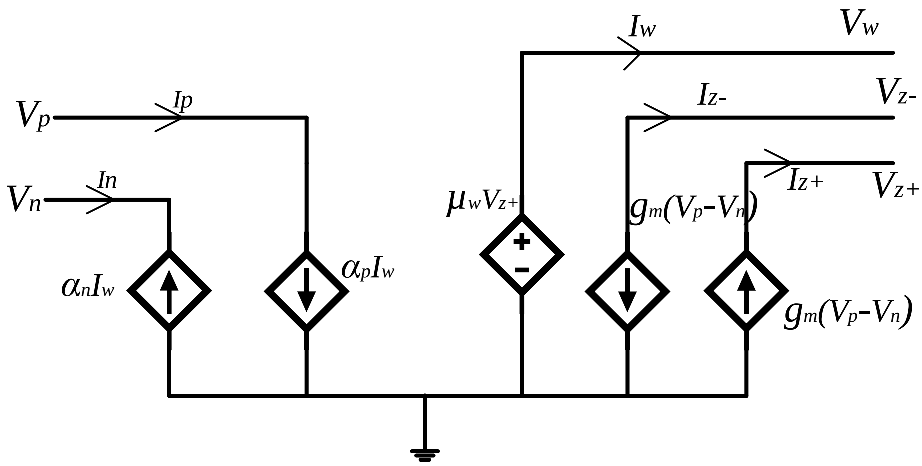

Fig 2.2 Equivalent symbol of CBTA [1]

2.2 Non-ideal CBTA

From the above mentioned terminal equations, the currents through terminals z^+ and , z^- follow the difference of voltages at the input terminals p, n and is multiplied by a factor of g_m, -g_m respectively. Therefore the output terminals $z^+ \ and \ z^-$ are current outputs, where the input terminal *p* is positive (noninverting), the input terminal *n* is negative (inverting). The voltage of *w* terminal follows the voltage of z^+. I_p, I_n, I_{Z^-}, I_{Z^+} and I_w are the currents at the terminals *p*, *n*, z^+, z^- and *w* terminals respectively. The voltages at the terminals are represented in the similar way. In the ideal case $g_m, \mu_p, \alpha_p, \alpha_n$ all the parameters are independent of frequency. In the ideal case only g_m is constant conductance(fixed for certain value of bias current) and all other parameters are equal to 1. But in practical case or non ideal case a slight deviation in the parameters from the value one can be observed. In the non ideal case the parameters of CBTA can be expressed as

$$\alpha_p(s) = \frac{\omega_p(1-\epsilon_p)}{(s+\omega_p)},$$

$$\alpha_n(s) = \frac{\omega_n(1-\epsilon_n)}{(s+\omega_n)},$$

$$g_m(s)=g_o\frac{\omega_g(1-\epsilon_g)}{(s+\omega_g)} \text{ and}$$

$\mu_w(s) = \frac{\omega_\mu(1-\epsilon_\mu)}{(s+\omega_\mu)}$ where $|\epsilon_p| \ll 1, |\epsilon_n| \ll 1, |\epsilon_g| \ll 1$ and $|\epsilon_\mu| \ll 1$. g_0 is the DC transconductance gain, ϵ_p and ϵ_n denote the current tracking errors, ϵ_μ denotes the voltage tracking error, ϵ_g denotes the transconductance error and $\omega_p, \omega_n, \omega_g, \omega_\mu$ denote corner frequencies.

In [1] a bipolar implementation of the CBTA has been given which is now presented. shown below in Fig.

2.3 BIPOLAR IMPLEMENTATION OF CBTA

The bipolar implementation results from the realization of different voltage and current transfers as given below:

$$I_{Z^+} = g_m(s)(V_p - V_n)$$

$$I_{Z^-} = g_m(s)(V_n - V_p)$$

$$V_W = \mu_w(s)V_{Z^+}$$

$$I_p = \alpha_p(s)I_w$$

$$I_n = -\alpha_n(s)I_w$$

The first two equations can be realized by a differential transconductor shown below in fig 2.4

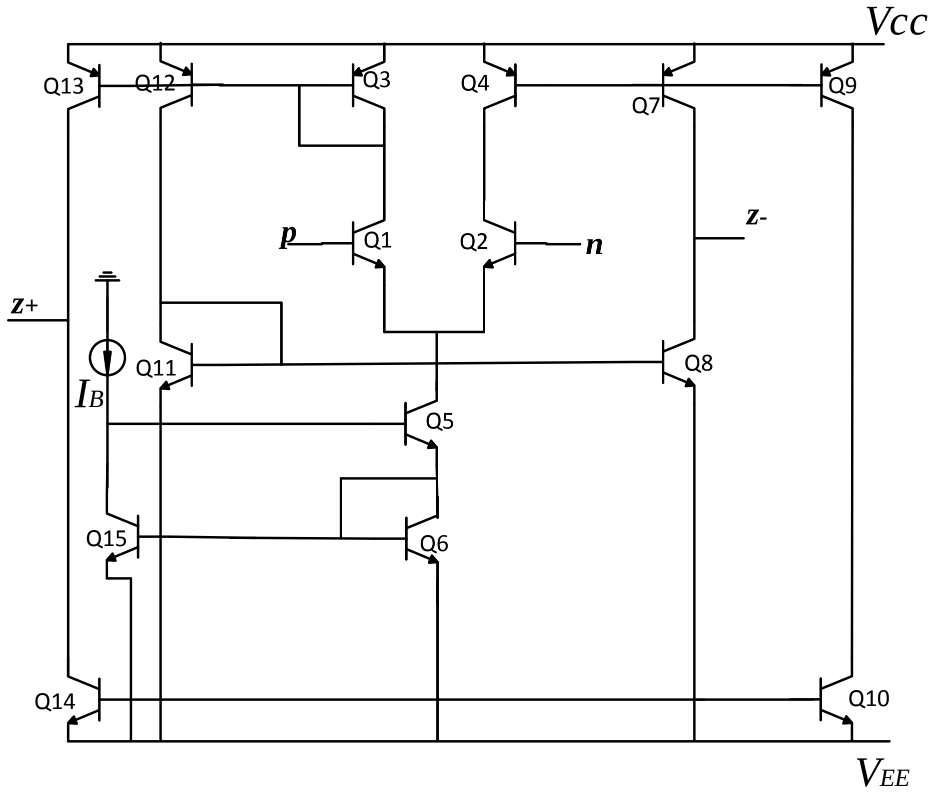

Fig 2.3 Transcondcutor section of CBTA

In the fig2.3 shown above the current through collector of Q3 is $\frac{g_m v_i}{2}$ downward and collector of Q4 is $\frac{-g_m v_i}{2}$ downward where v_i is the differential voltage between terminals p and n. The current through collectors of Q4 and Q7 are same, the current through collectors of Q11 and Q8 are same. The current through Z- terminal is sum of the collector currents of Q11, Q8 and is equal to $g_m v_i$ inward from Z- terminal. The current through collectors of Q4, Q7, Q9, Q10, Q14 are same and is equal to $\frac{-g_m v_i}{2}$ downward. The current through collectors of Q3, Q12, Q13 are $\frac{g_m v_i}{2}$ downward. The current through Z+ terminal is sum of the collector currents of Q13, Q14 and is equal to $g_m v_i$ outward.

The third equation can very easily be implemented by a translinear buffer and finally, the last two equations are implemented by current copier cells. These modules are given below in fig 2.4

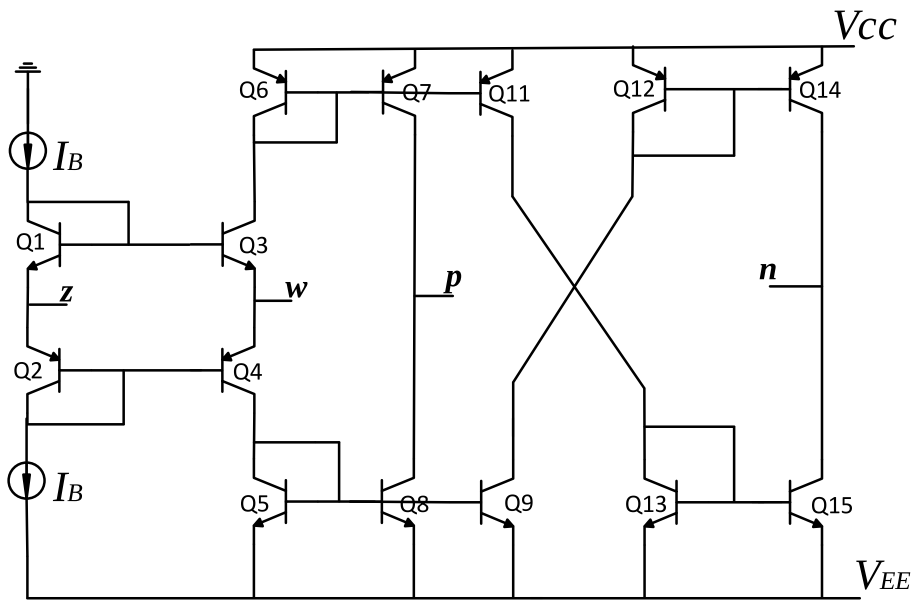

Fig 2.4 Voltage and current follower section of CBTA

The transistors Q1-Q4 is a translinear voltage buffer and is used to realize the terminal equation $V_W = \mu_w(s)V_{Z^+}$. The current through collectors of Q3, Q7 are same and the current through collectors of Q4, Q5, Q8 are same. Therefore the current through w and p terminal are same. By using cross coupling technique, the current through n terminal comes out be opposite in direction of current through w and p terminal.

The overall CBTA structure is given below in fig 2.5

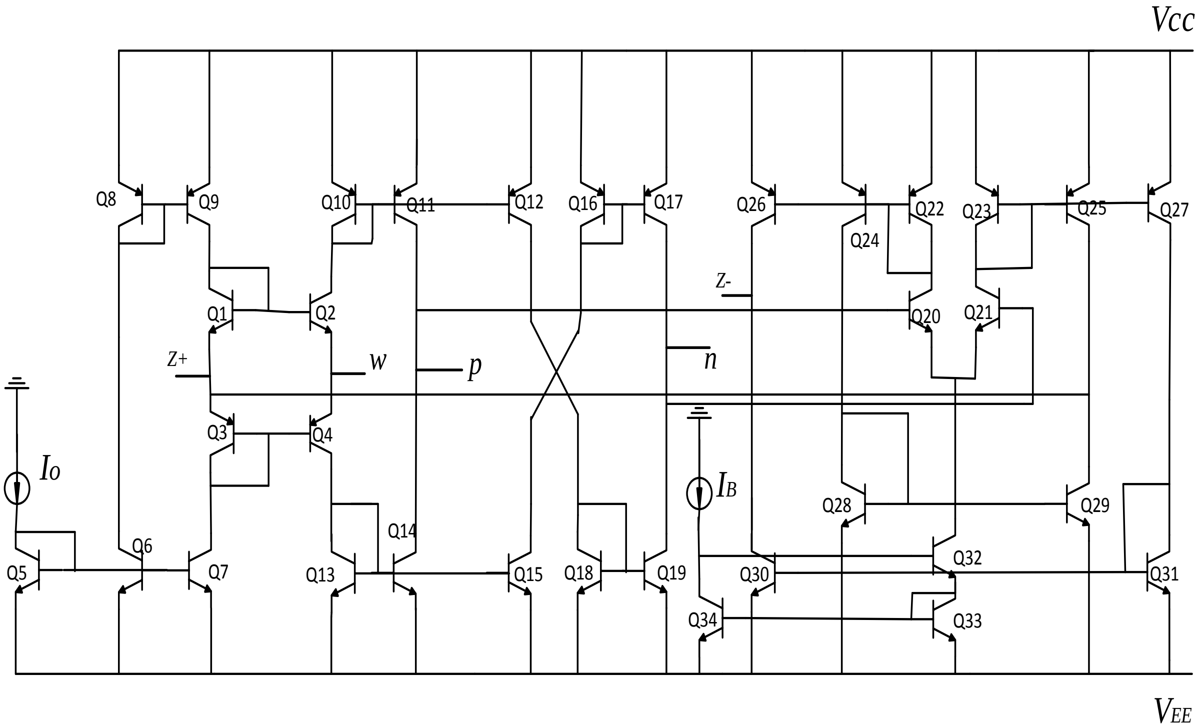

Fig 2.5 BJT Implementation of CBTA[1]

We now present the complete AC and DC characteristics of CBTA for various voltage and current transfers.

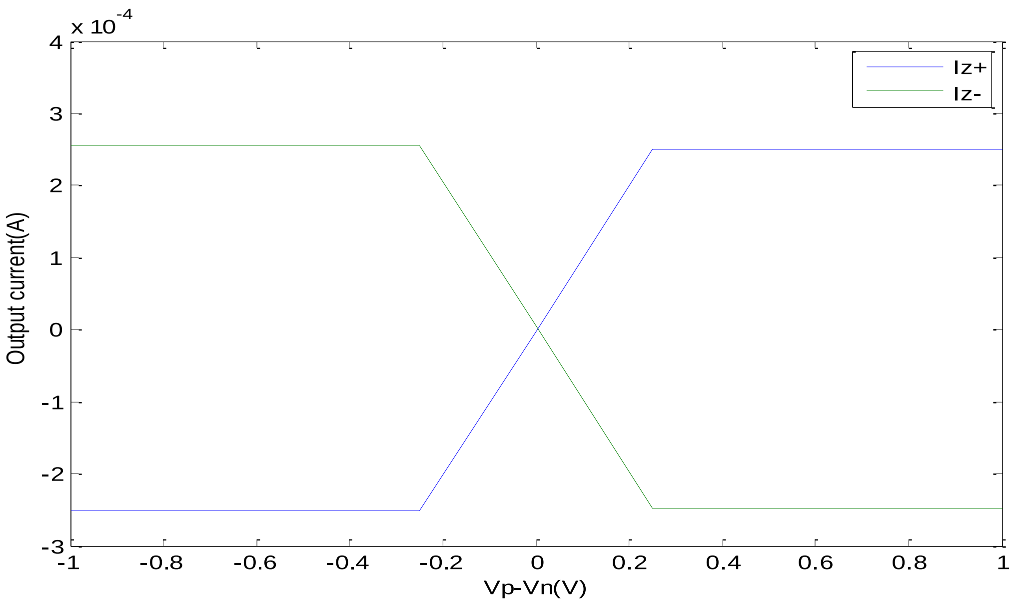

Fig 2.6 Transconductance transfer characteristics of CBTA

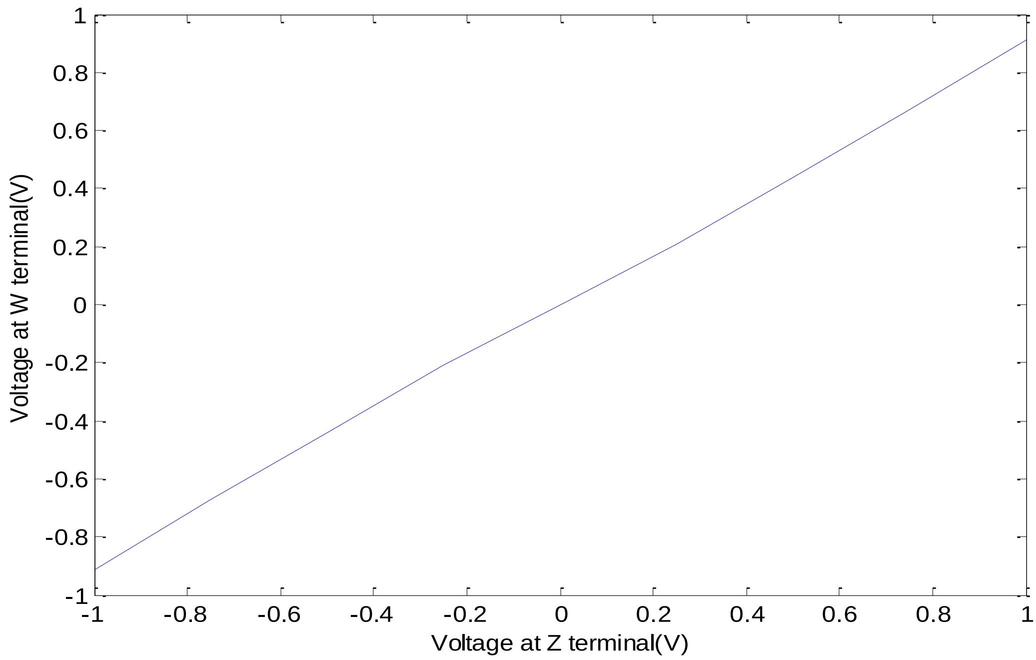

Fig 2.7 Voltage transfer characteristics of CBTA

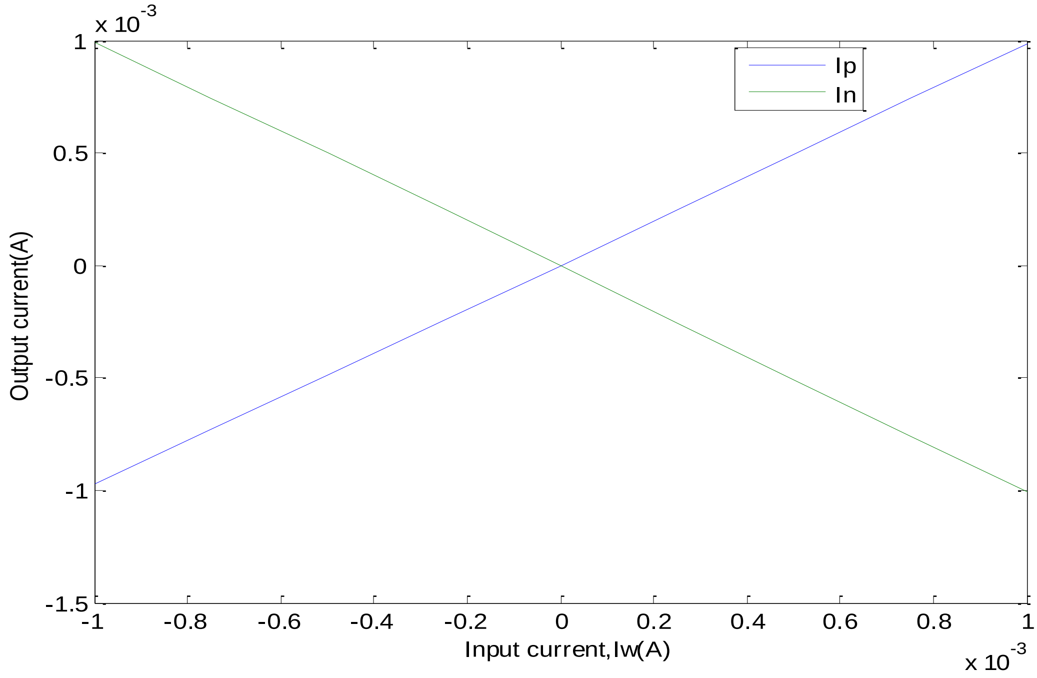

Fig 2.8 Current transfer characteristics of CBTA

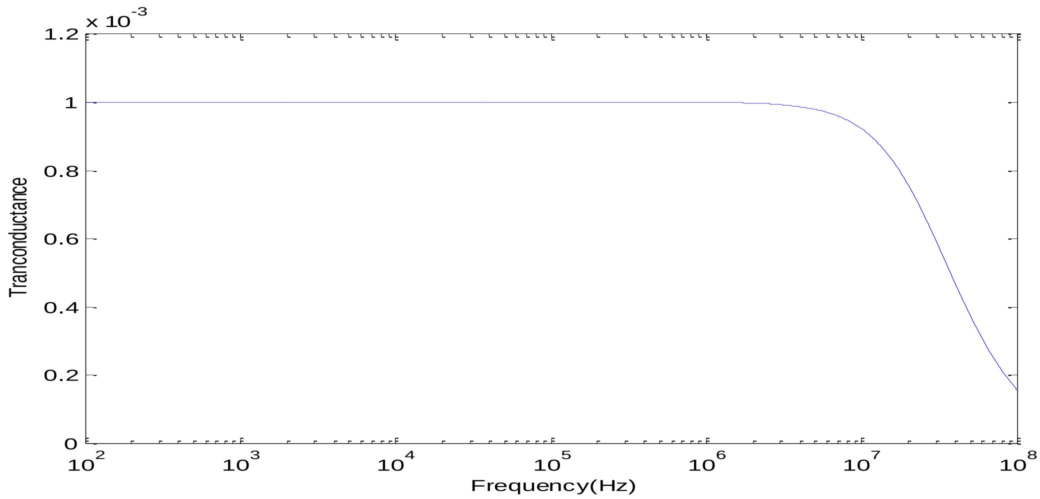

Fig 2.9 AC characteristics of transconductance of CBTA

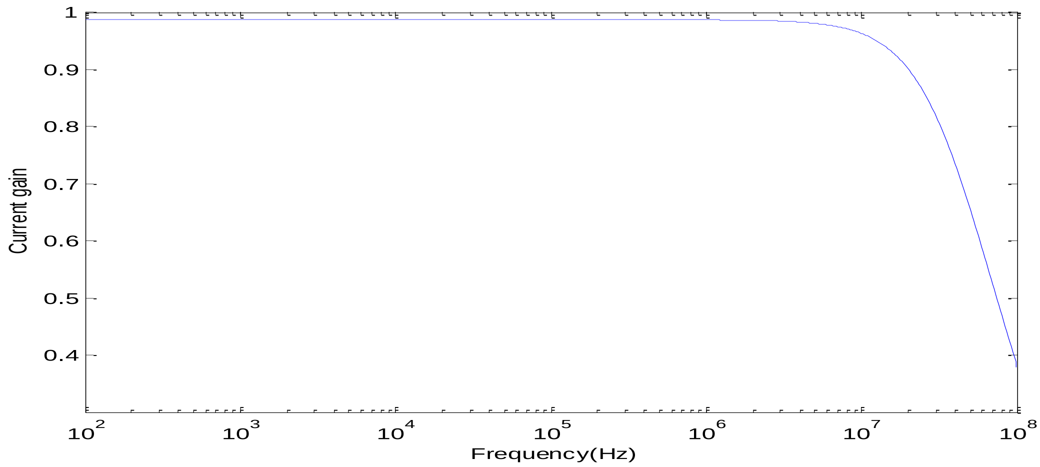

Fig 2.10 AC characteristics of current transfer of CBTA

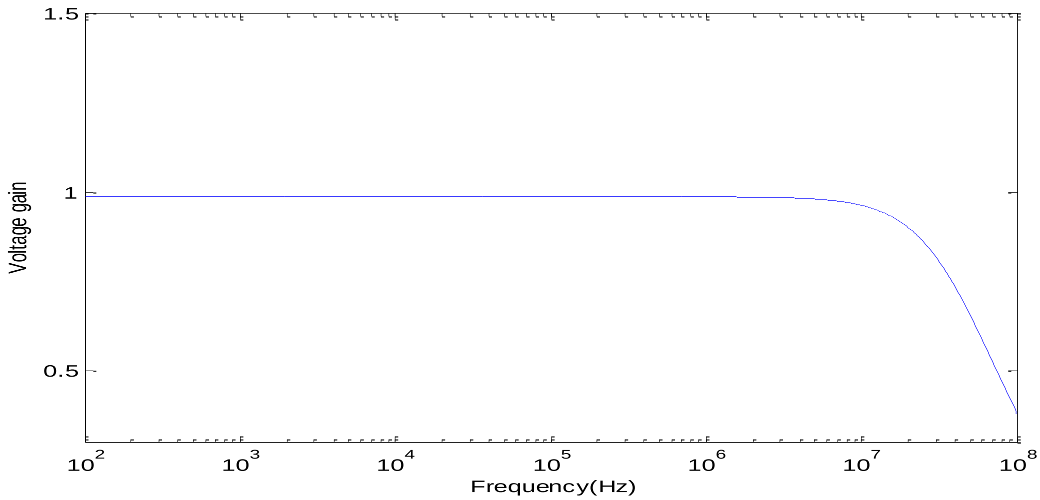

Fig 2.11 AC characteristics of voltage transfer of CBTA

2.4 Basic applications using CBTA:

2.4.1 Inverting Amplifier:

The input is given at inverting terminal, the non inverting terminal is grounded. The output is taken from z^+ terminal of CBTA. Resistor is connected at the Z terminal of CBTA. There is 180° phase shift between input and output.

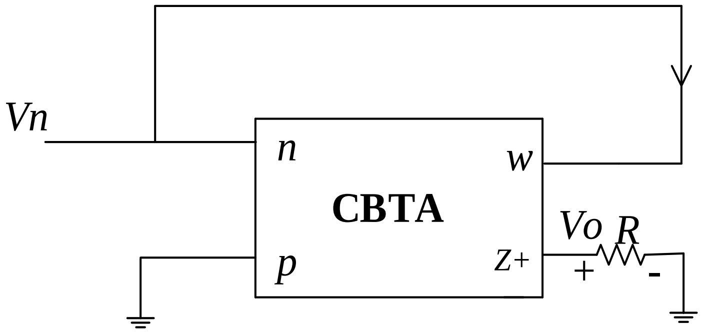

Fig 2.12 Inverting amplifier

We know that in CBTA, $I_{Z^+} = g_m(V_p - V_n)$ (2.1)

$V_w = \mu V_{z^+}$ (2.2)

When V_p=0, $I_{Z^+} = -g_m V_n$ from (2.1)

$V_{Z^+} = I_{Z^+} R_f$,

$V_{Z^+} = -g_m V_n R_f$, (2.3)

$V_w = -\mu g_m V_n R_f$

$V_o = V_{z^+}$

$\frac{V_o}{V_n} = -\mu g_m R_f$ is the equation of inverting amplifier where $\mu g_m R_f$ is the gain.

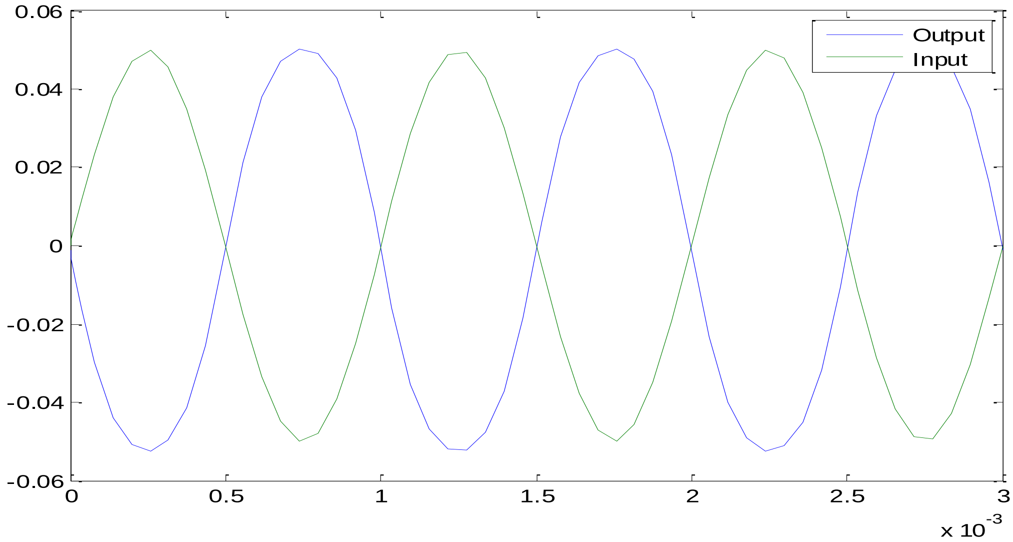

Fig 2.13 Time response of inverting amplifier using CBTA

The above figure gives the time response of inverting amplifier when g_m=1mS and R_f=1KΩ.

2.4.2 Non inverting amplifier:

The input given at non inverting terminal, the inverting terminal is grounded. The output is taken from z^+ terminal of the CBTA. Resistor is connected at the Z terminal of the active block. The will be 0° phase shift between input and output voltages.

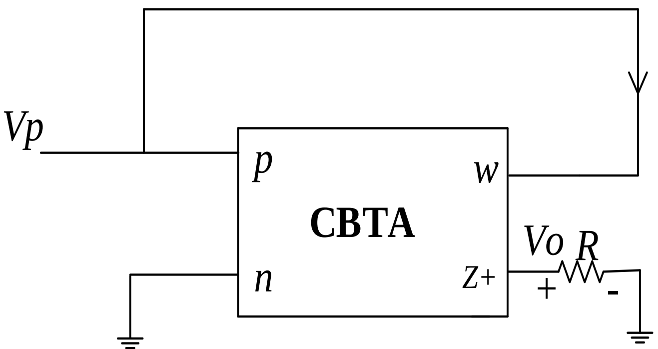

Fig 2.14 Non inverting amplifier

We know that in CBTA, $I_{Z^+} = g_m(V_p - V_n)$ (2.4)

$V_w = \mu V_{z^+}$ (2.5)

When V_n=0, $I_{Z^+} = g_m V_p$

from (2.4)

V_{Z^+}=$I_{Z^+}R_f$,

V_{Z^+}=$g_m V_p R_f$,   (2.6)

V_w=$\mu g_m V_p R_f$

V_o=V_{z^+}

$\frac{V_o}{V_p}$=$\mu g_m R_f$ is the equation of non inverting amplifier where $\mu g_m R_f$ is the gain.

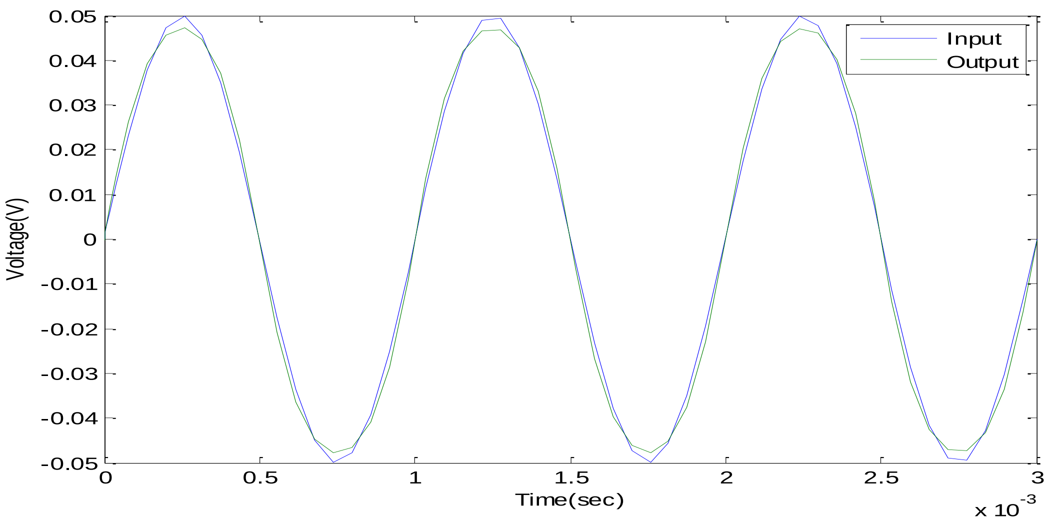

Fig 2.15 Time response of non-inverting amplifier using CBTA

In the above figure the time response characteristics of the non-inverting amplifier is shown when g_m=1mS and R_f=1KΩ.

2.5 Low pass filter design using CBTA

First order low pass filter is shown in the figure 2.16 below. It is designed with one capacitor and one CBTA. This is current mode filter for which the input current is given at node A and the output is taken from the terminal Z+. The transfer function for the output current taken from the terminal Z+ and the current through input current source represents a first order low pass filter.

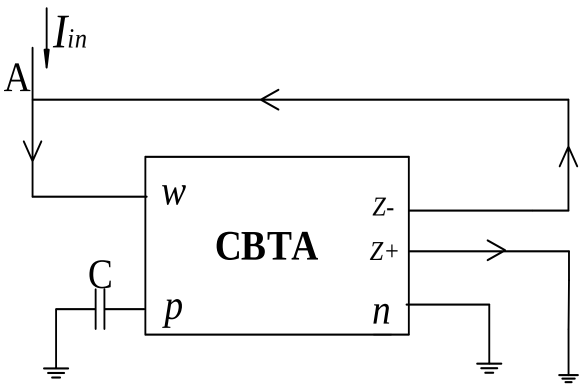

Fig 2.16 Low pass filter using CBTA[2]

$$I_{z+} = g_m(V_p - V_n) \qquad (2.7)$$

When V_n=0

$$I_{z+} = g_m V_p \qquad (2.8)$$

From the above diagram writing KCL at node A,

$$I_{in} = I_w - I_{z-} \qquad (2.9)$$

$$I_{in} = I_w - g_m V_p \qquad (2.10)$$

$$I_p = \alpha_p I_w \qquad (2.11)$$

$$V_p = -\frac{I_p}{sc} \qquad (2.12)$$

$$V_p = -\frac{\alpha_p I_w}{sc} \qquad (2.13)$$

Substituting equation (2.13) in equation (2.10)

$$I_{in} = I_w + \frac{\alpha_p g_m I_w}{sc} \qquad (2.14)$$

$$I_{in} = I_w \frac{(sc+g_m\alpha_p)}{sc} \qquad (2.15)$$

$$I_{z+} = \frac{-g_m\alpha_p I_w}{sc} \qquad (2.16)$$

Dividing equation (2.16) by (2.15)

$$\frac{I_{z+}}{I_{in}} = \frac{-g_m\alpha_p}{(sc+g_m\alpha_p)} \qquad (2.17)$$

The above equation gives the transfer function of the first order low pass filter using the new active block CBTA.

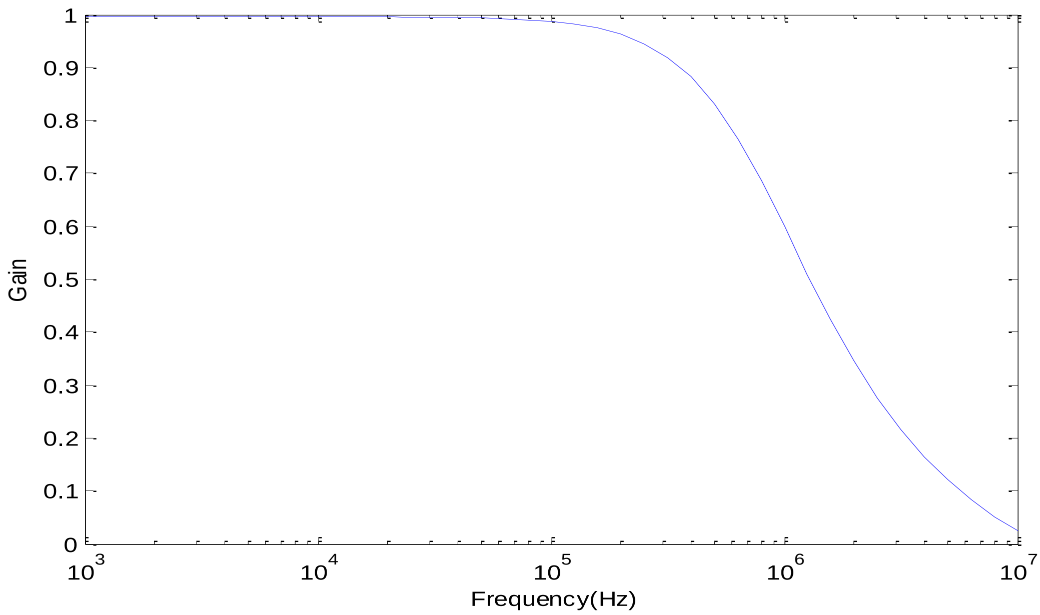

Fig 2.17 Frequency response of first order low pass filter using CBTA

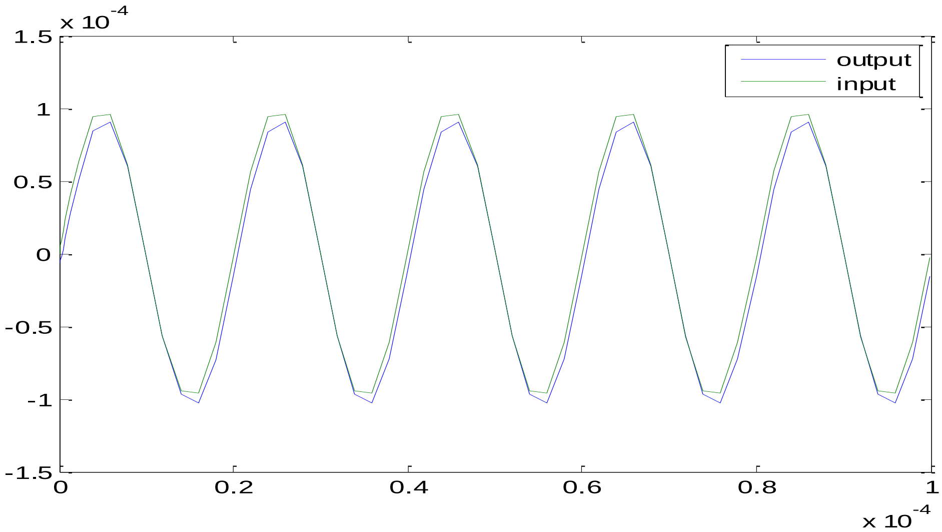

Fig 2.18 Time response of low pass filter using CBTA

The low pass filter is designed for cut-off frequency 1MegaHz with g_m=1mS and C=1nF. From the frequency response the cut-off frequency is 985KHZ. Time response of the first order low pass filter using CBTA is shown in the figure 2.18 where the frequency of the input signal is 50KHZ.

2.6 High pass filter design using CBTA

First order high pass filter is shown in the below fig 2.19. It consists of one CBTA, one capacitor. This is current mode high pass filter. In this circuit input current is given at the node A and the output current is taken at the terminal n. The transfer function for the output current at the terminal n and the input current represents a first order high pass filter.

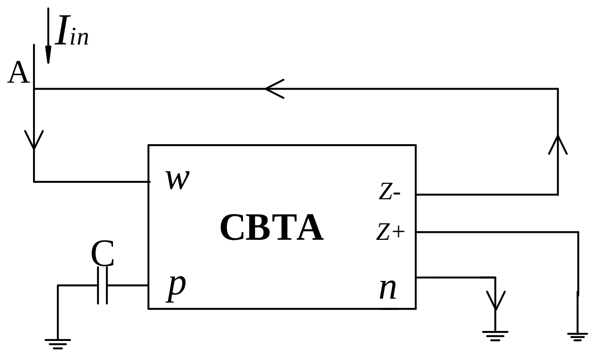

Fig 2.19 High pass filter circuit using CBTA[2]

$$I_{z+} = g_m(V_p - V_n) \qquad (2.18)$$

$$I_n = -\alpha_n I_w \qquad (2.19)$$

$$I_{in} = I_w - I_{z-} \qquad (2.20)$$

$$I_{z-} = -g_m V_p \qquad (2.21)$$

$$I_{in} = I_w + \frac{g_m \alpha_p I_w}{sc} \qquad (2.22)$$

$$I_{in} = I_w \frac{(sc + g_m \alpha_p)}{sc} \qquad (2.23)$$

Dividing equation (2.19) by equation (2.23)

$$\frac{I_n}{I_{in}} = \frac{-sc\alpha_n}{(sc + g_m \alpha_p)} \qquad (2.24)$$

The above transfer function represents first order high pass filter realised using CBTA.

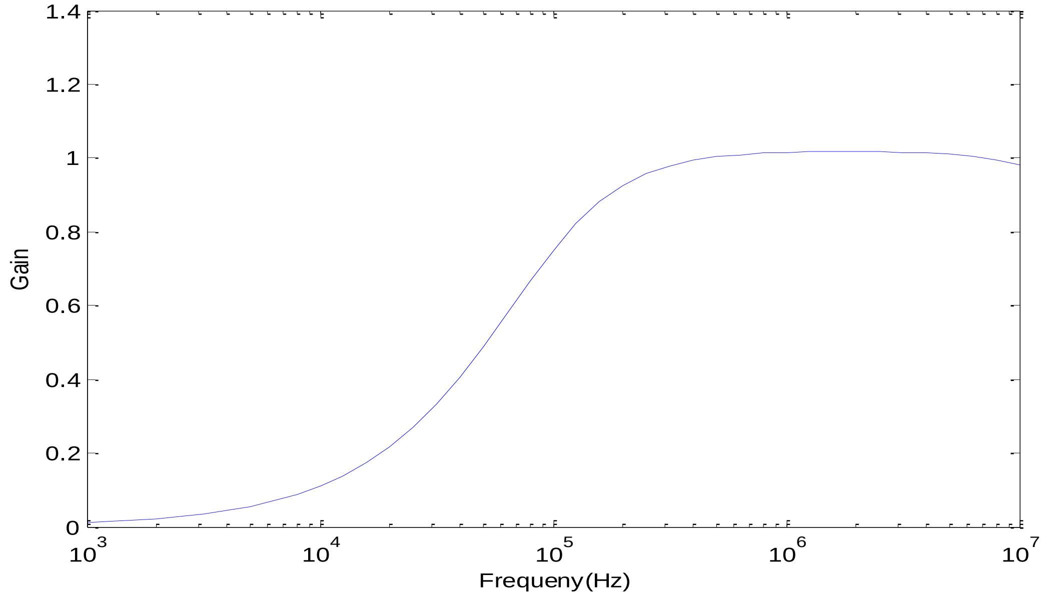

Fig 2.20 Frequency response of high pass filter using CBTA

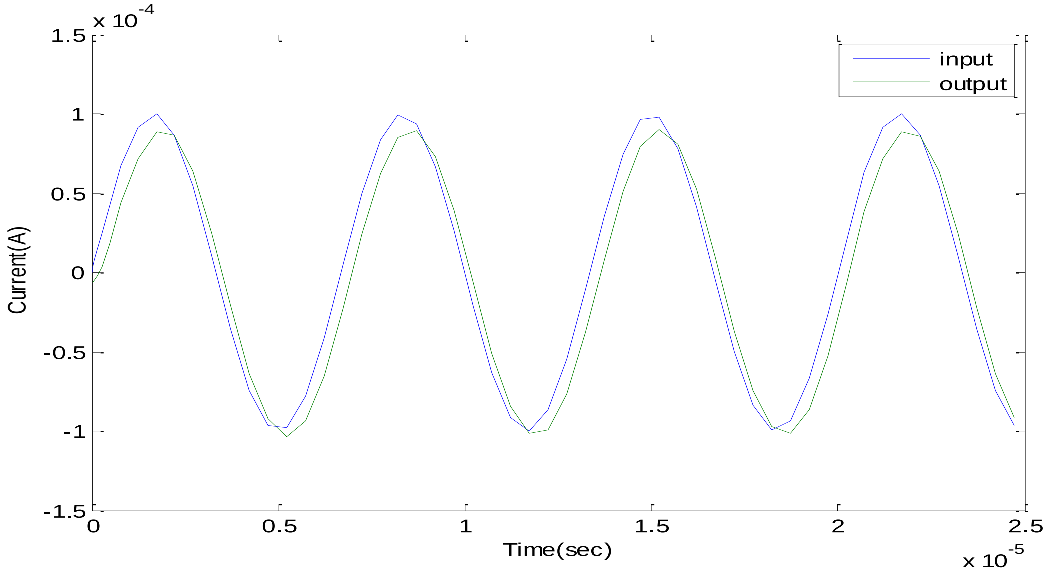

Fig 2.21 Time response of High pass filter using CBTA

The high pass filter is designed for cut-off frequency 100KHZ for g_m=1mS and C=10nF. Time response of the first order low pass filter using CBTA is shown in the figure 2. 21 where the frequency of the input signal is150KHZ.

2.7 ALL PASS FILTER USING CBTA

The all pass filter implemented [3] using CBTA is shown in the fig 2.22 given below. The implemented[3] all pass filter consists of one CBTA, one capacitor and one inductor. In the all pass filter circuit input current is applied at terminal w. The output current is taken from the terminal z+. The transfer function of the output current at terminal z+ to the input current at terminal w will give an all pass filter function.

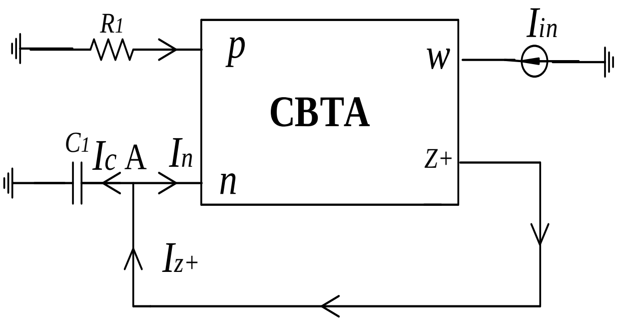

Fig 2.22 All pass filter circuit using CBTA[3]

$$I_{z+} = g_m(V_p - V_n) \quad (2.25)$$

$$I_p = \alpha_p I_w \quad (2.26)$$

$$I_n = -\alpha_n I_w \quad (2.27)$$

$$V_n = \frac{I_c}{sc_1} \quad (2.28)$$

Writing KCL at node A,

$$I_{z+} = I_c + I_n \quad (2.29)$$

$$I_c = I_{z+} - I_n \quad (2.30)$$

Substituting equation (2.30) in equation (2.28)

$$V_n = \frac{I_{z+} - I_n}{sc_1} \quad (2.31)$$

$$V_p = -\alpha_p I_w R_1 \quad (2.32)$$

Substitute equation (2.31) and (2.32) in equation (2.25)

$$I_{z+} = g_m(-\alpha_p I_w R_1 + \frac{\alpha_n I_w - I_{z+}}{sc_1}) \qquad (2.33)$$

$$I_{z+}(1+\frac{g_m}{sc_1}) = g_m \frac{(-sc_1\alpha_p I_w + \alpha_n I_w)}{sc_1} \qquad (2.34)$$

From the circuit $I_w = -I_{in}$ (2.35)

Substituting equation (2.35) in (2.34)

$$\frac{I_{z+}}{I_{in}} = \frac{(sg_m R_1 - \frac{g_m}{c_1})}{(s+\frac{g_m}{c_1})} \qquad (2.36)$$

When $R_1 = \frac{1}{g_m}$ the above transfer function represents an all pass filter using the CBTA.

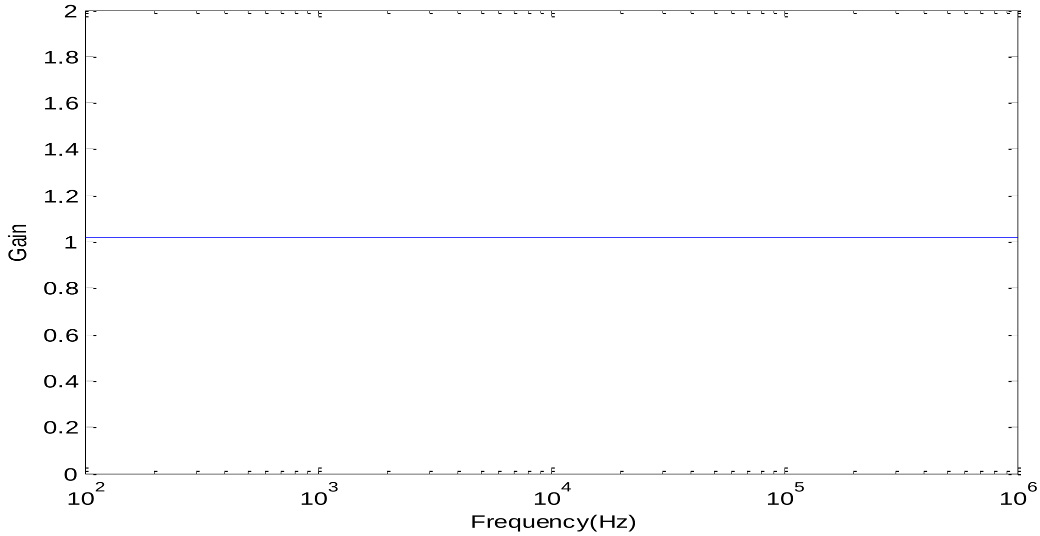

Fig 2.23 Frequency response of all pass filter

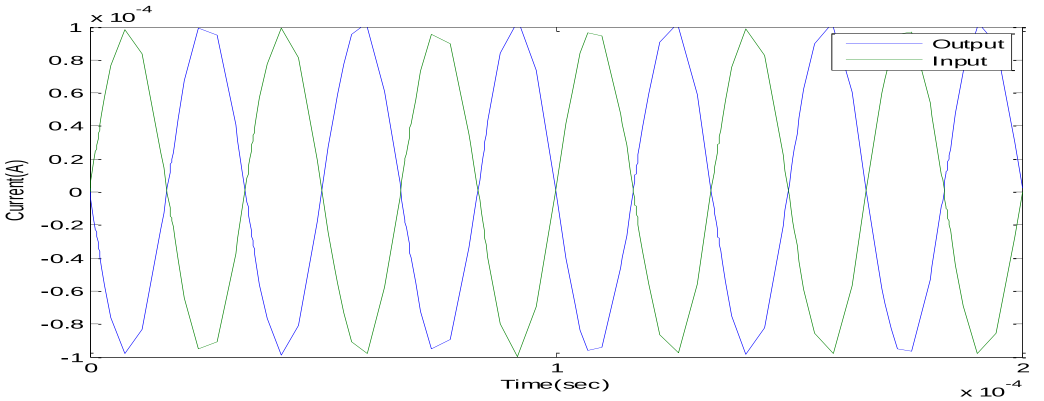

Fig 2.24 Time response of all pass filter

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2.8 Conclusion:

In this chapter we have presented the bipolar implementation of CBTA which is a 5 terminal active device represented by the terminals p, n, w, z+, z-. This device can be operated in both voltage mode and current mode applications. For the voltage mode of operation voltage is given at the terminals p and n. For the current mode applications current is given at the terminal w. The various characteristics of CBTA namely transconductance characteristics, current transfer characteristics and voltage transfer current characteristics had been represented in the form of graphs and were verified against the equations for those characteristics.

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International Journal of Circuit Theory and Applications, vol. 36, no. 4, pp. 511-522, 2008.

CHAPTER 3

REALISATION OF GROUNDED INDUCTOR AND FLOATING INDUCTOR USING CBTA

3.1 Introduction

In this chapter electronically controllable lossless grounded inductance and floating inductance simulators using two passive elements one capacitor, one resistor and current backward transconductance amplifier are implemented.

One of the conventional issues in the design of radio frequency(RF) circuits is related to the realization of integrated inductors with high quality factor. It is very well known that, using standard silicon process, it is not possible to realize passive inductors that exhibit simultaneously high-quality factor (e.g., Q > 10), high inductance value (e.g., a few nH) and high cost additional steps into the fabrication process.

Inspite of many circuits and methodologies which were already proposed and investigated, the term active inductors (AIs) which had appeared in the title of a paper in the early 1970s [1]. Later, efficient realisations of selective active filters on silicon, i.e., bipolar technology, were proposed in the 1990s[2].

Many simulated grounded inductors (GI) and floating inductors using different active blocks such as op-amps, CCs, CFOAs, FTFNs, CDBAs, CFTAs have been implemented, but they suffer from following disadvantages:

1.) Requirement for more number of passive components,
2.) Requires more number of active elements,
3.) Realised inductor is lossy.

Recently CBTA was introduced and it can be operated in both current mode and voltage mode applications. In the following we present a brief review of some important works on realization of grounded and floating inductors using these blocks.

3.2 INDUCTOR SIMULATOR USING CDTA

3.2.1 Grounded and floating inductors using CDTA

The lossless inductor developed from CDTA is shown in the figure 3.1 below

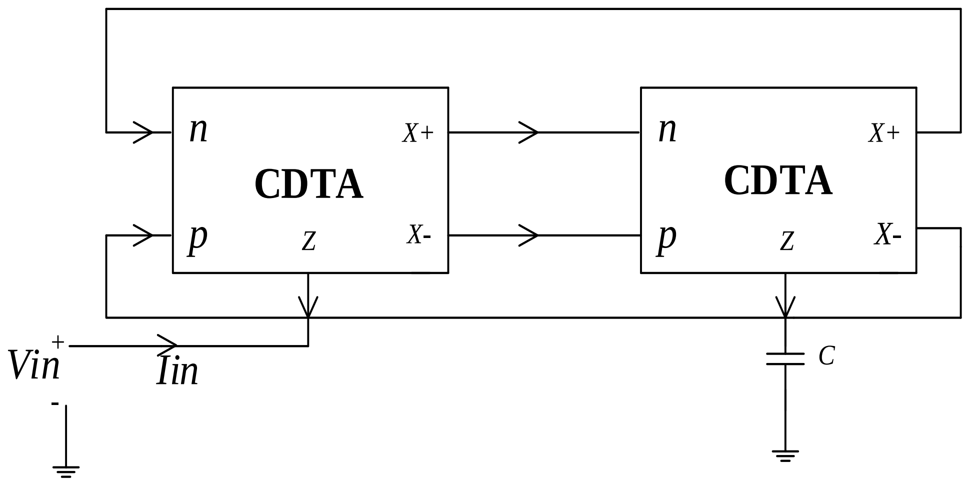

Fig 3.1 Grounded inductor using CDTA [5]

Ideal characteristics of CDTA is given by

$$V_p = V_n = 0, \quad (3.1)$$

$$I_p - I_n = I_z, \quad (3.2)$$

$$I_{X+} = g_m V_z, \quad (3.3)$$

$$I_{X-} = -g_m V_z, \quad (3.4)$$

From the fig 3.1 voltages and currents at particular node are given by

$$I_{in} = -I_{z1} \quad (3.5)$$

$$I_{in} = 2g_{m2}V_{z2} \quad (3.6)$$

$$I_{in} = 2g_{m2}\frac{I_{z2}}{sc} \quad (3.7)$$

$$I_{in} = \frac{4g_{m1}g_{m2}}{sc}V_{in} \quad (3.8)$$

Thus the circuit in fig 3.1 gives a inductance of equivalent value $L_{eq}=\frac{sc}{4g_{m1}g_{m2}}$.

Where $g_{m1,}g_{m2}$ are transconductances of CDTA1 and CDTA2.

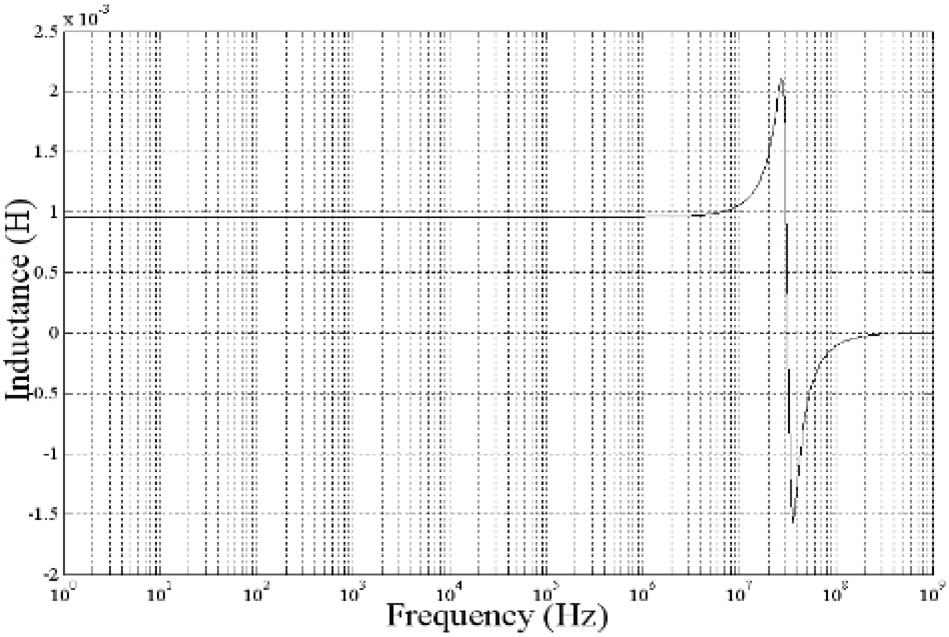

Fig 3.2 Frequency response of grounded inductor using CDTA [5]

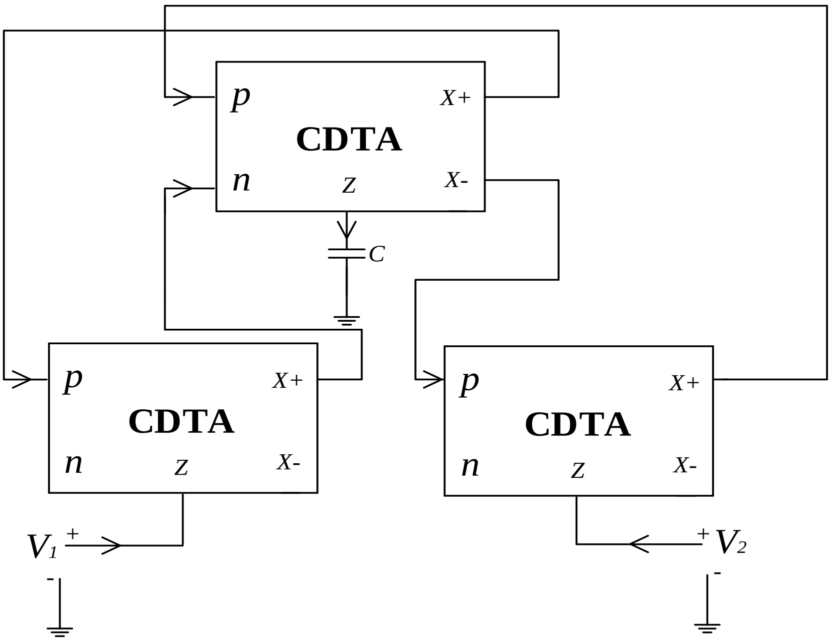

Fig 3.3 Floating inductance using CDTA [5]

Analysing the figure 3.3, we get

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{g_{m3}g_m}{sc}\begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{3.9}$$

When $g_{m1}=g_{m2}=g_m$ the circuit in the fig 3.3 simulates a floating lossless inductance with the resulting inductance value given by

$$L_{eq} = \frac{c}{g_{m3}g_m} \quad (3.10)$$

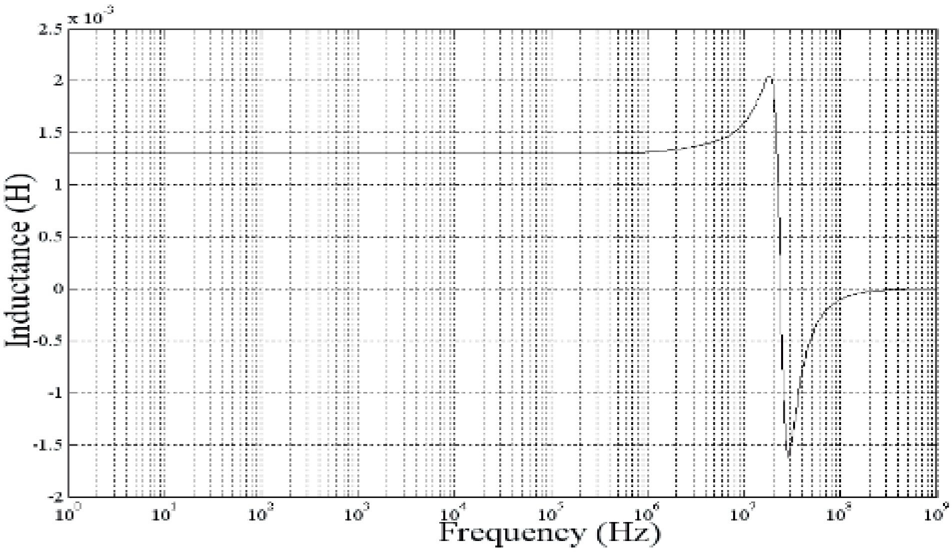

Fig 3.4 Frequency response of floating inductance using CDTA [5]

3.3 Inductor simulator using VDTA

VDTA is a 5 terminal active device of which two are inputs terminals and three are output terminals. All the terminals of VDTA exhibit high impedance value.

3.3.1 Grounded inductor using VDTA

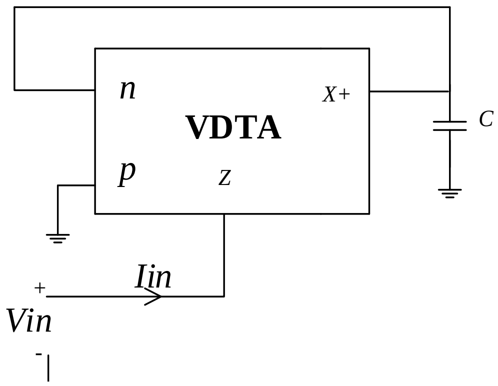

Fig 3.5 Grounded inductor using VDTA [7]

From the circuit analysis of the circuit shown in the figure 3.5, the expression for the input impedance is given by

$$Z_{in} = \frac{V_{in}}{I_{in}} = s\frac{C}{g_{m1}g_{m2}} \quad (3.11)$$

From the above equation the equivalent inductance of the circuit shown in the figure 3.5 is given by

$$L_{eq} = \frac{C}{g_{m1}g_{m2}} \quad (3.12)$$

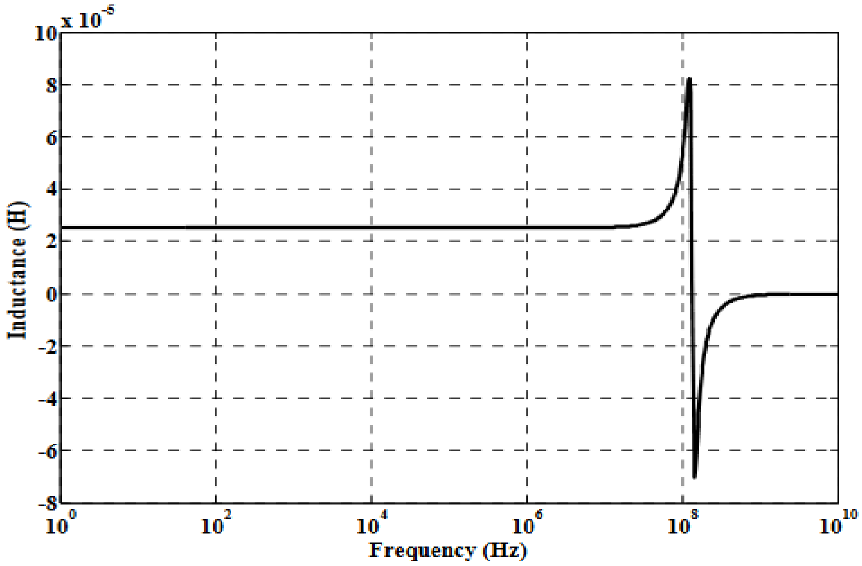

Fig 3.6 Frequency response of grounded inductor using VDTA [7]

3.3.2 Floating inductor using VDTA

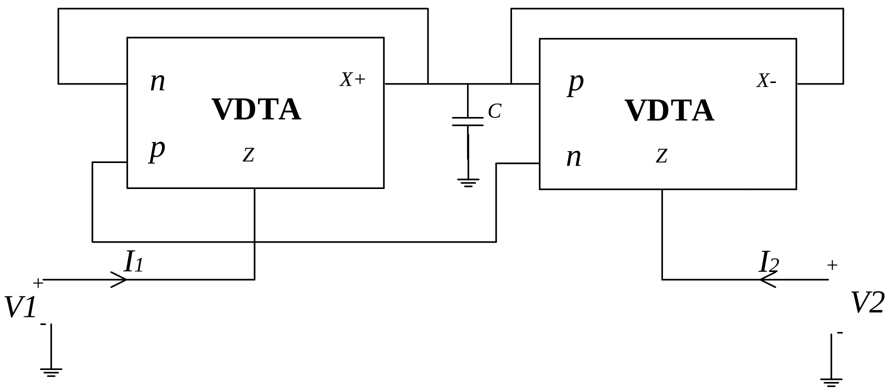

Fig 3.7 Floating inductor using VDTA [7]

The analysis of the floating inductance simulation circuit in the fig 3.7 is given by

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{g_{m1}g_{m2}}{sc}\begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad (3.13)$$

From the above equation the equivalent inductance is given by

$$L_{eq} = \frac{C}{g_{m1}g_{m2}} \quad (3.14)$$

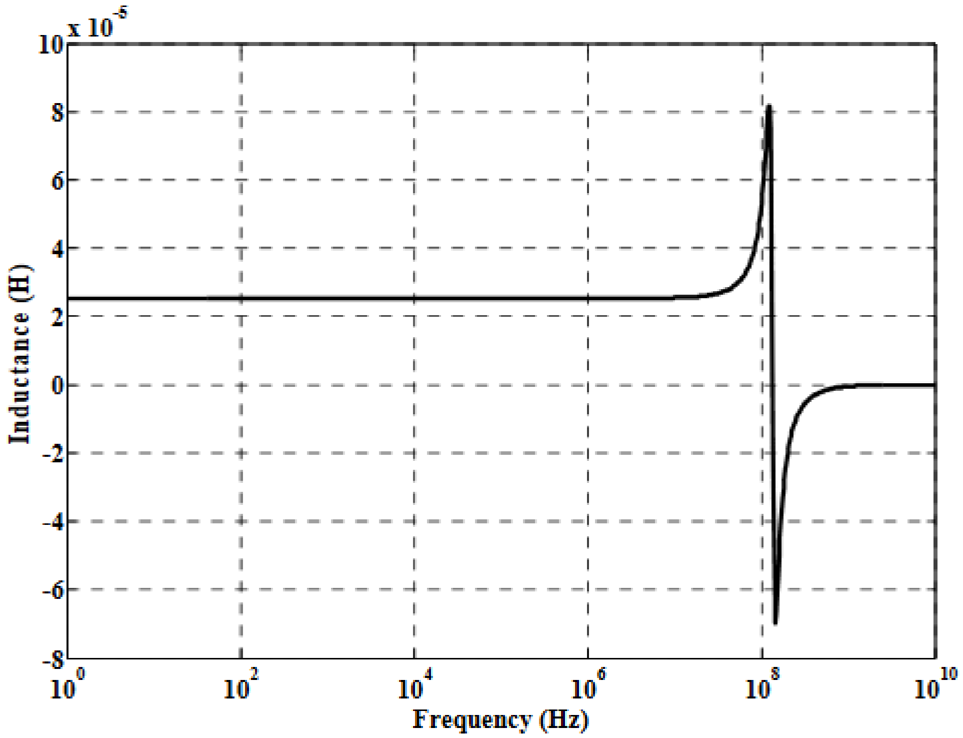

Fig 3.8 Frequency response of the floating inductor using VDTA [7]

3.4 Grounded inductor simulator using VDCC

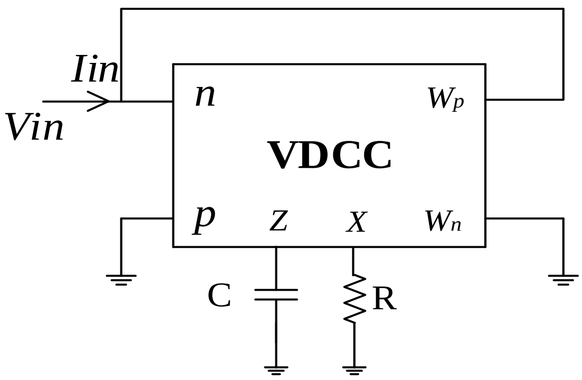

Fig 3.9 Grounded inductor using VDCC[13]

The grounded inductor circuit is constructed with single VDCC, one capacitor and one resistor. The above circuit result in an inductor whose value is given by

$$L_{eq} = \frac{C_1 R_1}{g_m} \quad (3.15)$$

3.4.1 FLOATING INDUCTOR USING VDCC

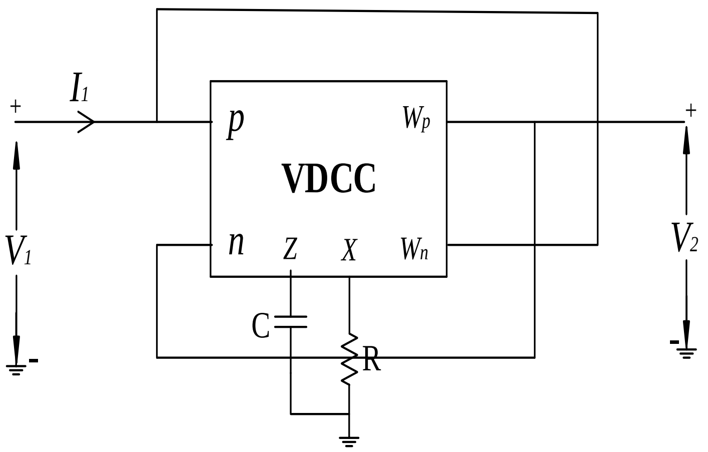

Fig 3.10 Floating inductor using VDCC[13]

The analysis of the above circuit results in the Y parameters of the following form

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{g_m}{sCR} \begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{3.16}$$

Which indicates the simulated floating inductor has inductance value of

$$L_{eq} = \frac{CR}{g_m} \tag{3.17}$$

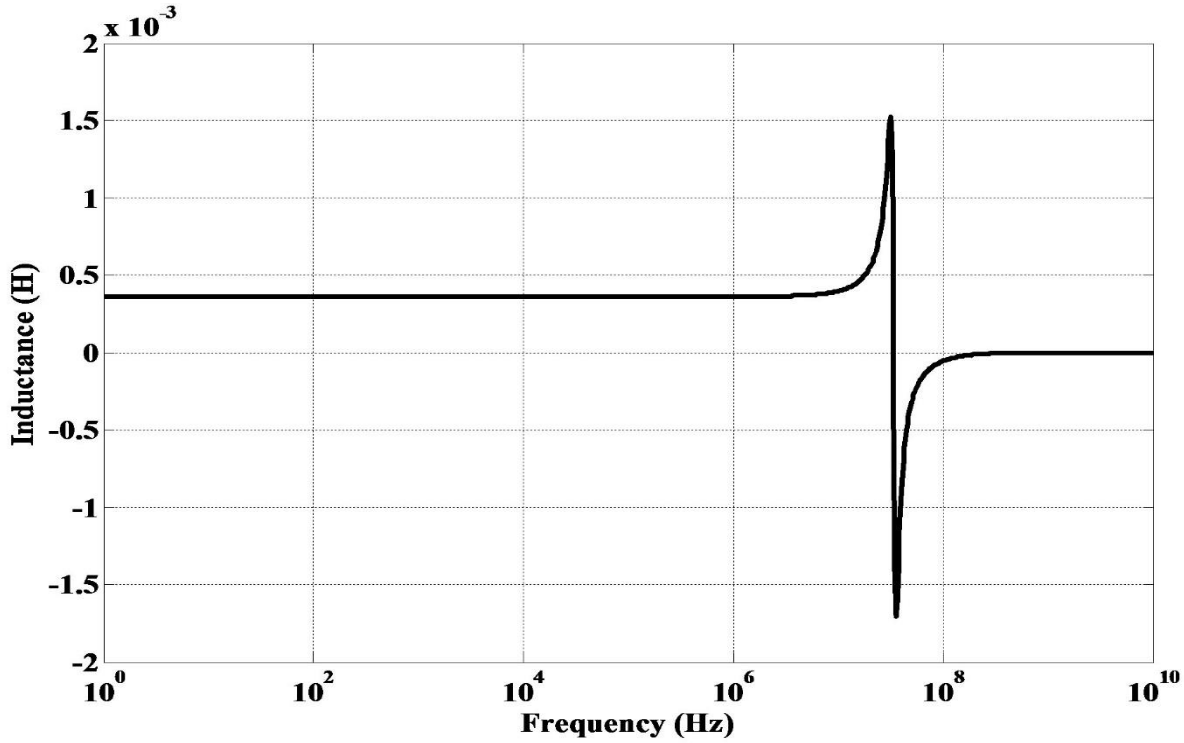

Fig 3.11 Floating inductance graph using VDCC[13]

3.5 GROUNDED INDUCTOR USING VD-DIBA

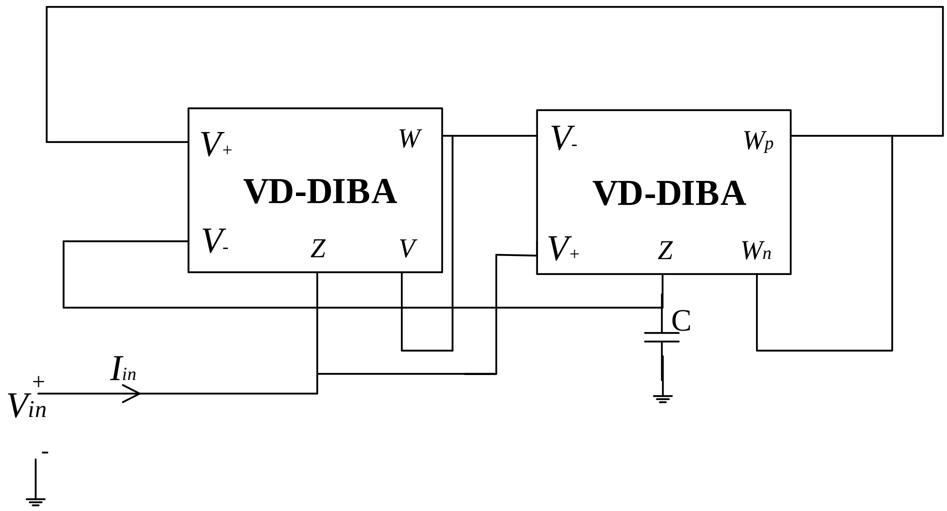

Fig 3.12 Grounded inductor using VD-DIBA[12]

Analysing the circuit given in the above fig 3.12 the equivalent inductance value is given by

$$L_{eq} = \frac{c}{g_{m1}g_{m2}} \qquad (3.18)$$

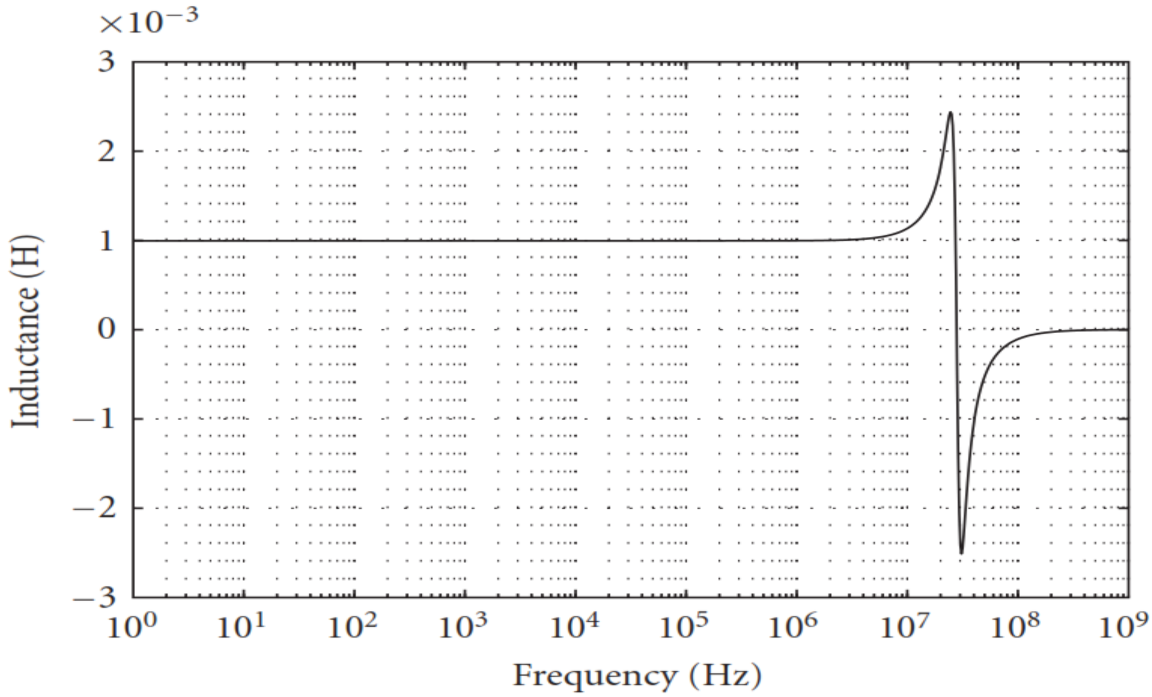

Fig 3.13 Frequency response of grounded inductor using VD-DIBA[12]

3.5.1 FLOATING INDCUTOR USING VD-DIBA

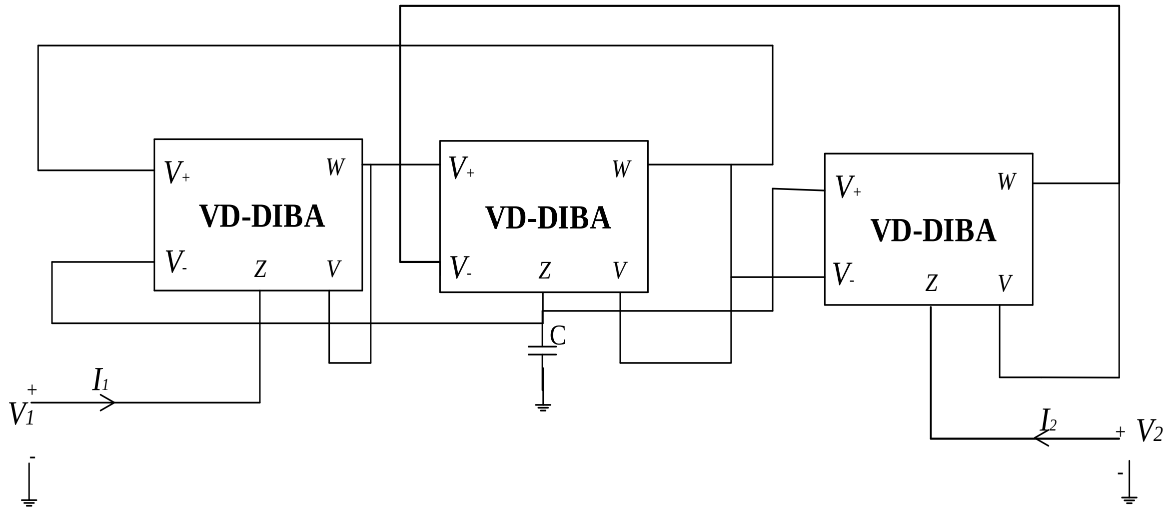

Fig 3.14 Floating inductor using VD-DIBA[12]

Input and output currents in the fig 3.14 are related by the relation

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \frac{g_{m1} g_{m2} R_z \beta_1 (2-\beta_2)}{4s(c+c_z)(R_z+1)} \begin{bmatrix} +1 & -1 \\ -1 & +1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{3.19}$$

The equivalent inductance of the above circuit is given by

$$L_{eq} = \frac{g_{m1} g_{m2} R_z \beta_1 (2-\beta_2)}{4s(c+c_z)(R_z+1)} \tag{3.20}$$

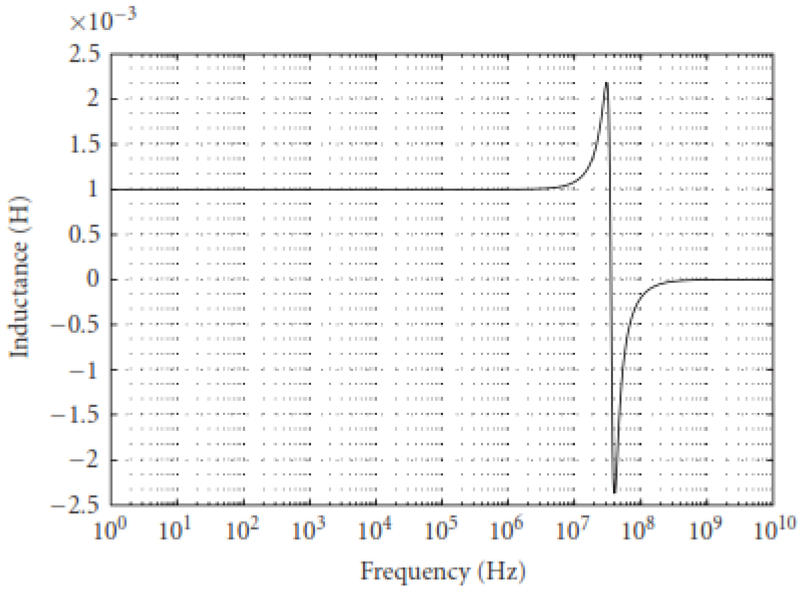

Fig 3.15 Frequency response of floating inductor using VD-DIBA[12]

3.6 GROUNDED INDUCTOR SIMULATOR USING CBTA

Grounded inductor simulator using CBTA is shown in figure 3.16. This circuit is designed with single CBTA, one grounded capacitor and one grounded resistor. In this circuit the terminal n is grounded and the voltage is given at the terminal p. The transfer function for the voltage applied at the terminal p to the current entering the terminal p represents a grounded inductor as one end of the inductor is connected to the ground.

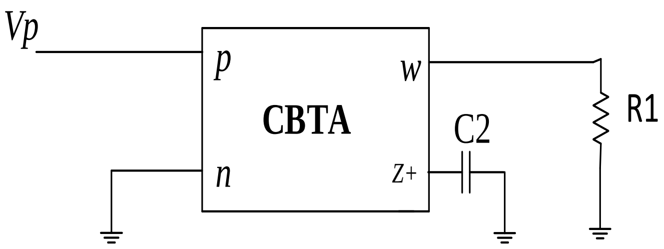

Fig 3.16 Grounded inductor simulator using CBTA[4]

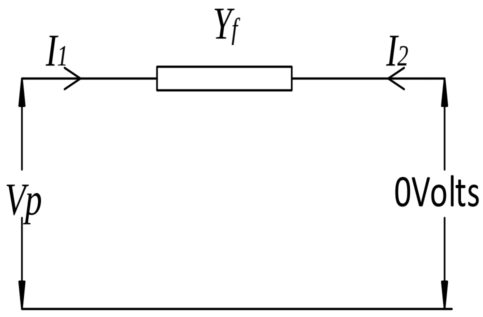

Fig 3.17 Equivalent symbol of grounded inductor

$$I_{z+}=g_m(V_p - V_n) \tag{3.21}$$

$$V_{z+}=\frac{I_z}{Y_2} \tag{3.22}$$

$$V_w=\mu V_z \tag{3.23}$$

$$V_w=\mu g_m(V_p - V_n) \tag{3.24}$$

Here V_n=0

$$I_w=V_w Y_1 \tag{3.25}$$

$$I_w=\frac{\mu g_m V_p Y_1}{Y_2} \tag{3.26}$$

$$I_p = \alpha I_w \tag{3.27}$$

$$I_p=\frac{\alpha\mu g_m V_p Y_1}{Y_2} \tag{3.28}$$

When $Y_1 = \frac{1}{R_1}$, $Y_2 = SC_2$ the above equation will represent grounded inductor.

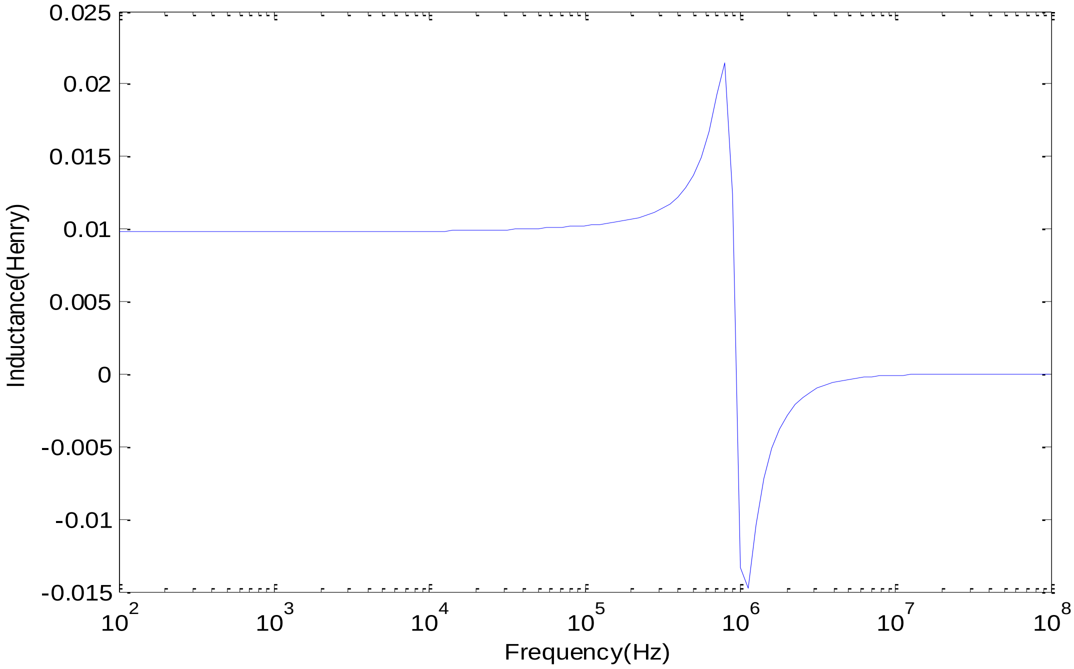

Fig 3.18 Graph of grounded inductance simulator

Grounded simulator is simulated in PSPICE using CBTA where the value of g_m=1mS, $C_1 = nF$, and $R_1 = 10K\Omega$.

3.7 FLOATING INDUCTANCE SIMULATOR USING CBTA

Floating inductor using CBTA is shown in the figure 3.19. Floating inductance is designed using one CBTA one capacitor and one resistor. For realising the floating inductance voltage is given at both p and n terminals. The transfer function for the voltage difference between p and n terminals to the current entering the p terminal represents floating inductor.

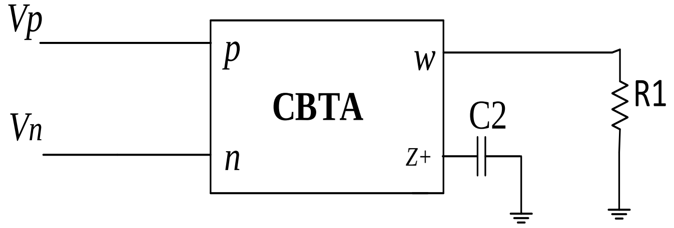

Fig 3.19 Symbol of floating inductance simulator[4]

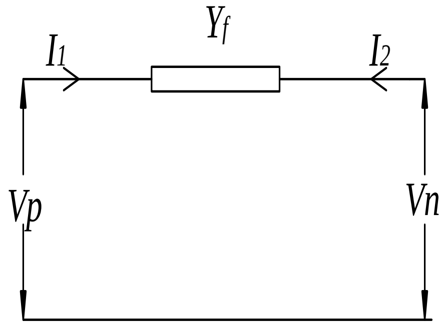

Fig 3.20 Equivalent circuit of floating inductance

$$I_{z+}=g_m(V_p - V_n) \tag{3.29}$$

$$V_{z+}=\frac{I_z}{Y_2} \tag{3.30}$$

$$V_w=\mu V_z \tag{3.31}$$

$$V_w=\mu g_m(V_p - V_n) \tag{3.32}$$

$$I_w=V_w Y_1 \tag{3.33}$$

$$I_w=\frac{\mu g_m V_p Y_1}{Y_2} \tag{3.34}$$

$$I_p = \alpha I_w \tag{3.35}$$

$$I_p=\frac{\alpha\mu g_m(V_p - V_n)Y_1}{Y_2} \tag{3.36}$$

When $Y_1=\frac{1}{R_1}$, $Y_2 = SC_2$ the above equation will represent floating inductor.

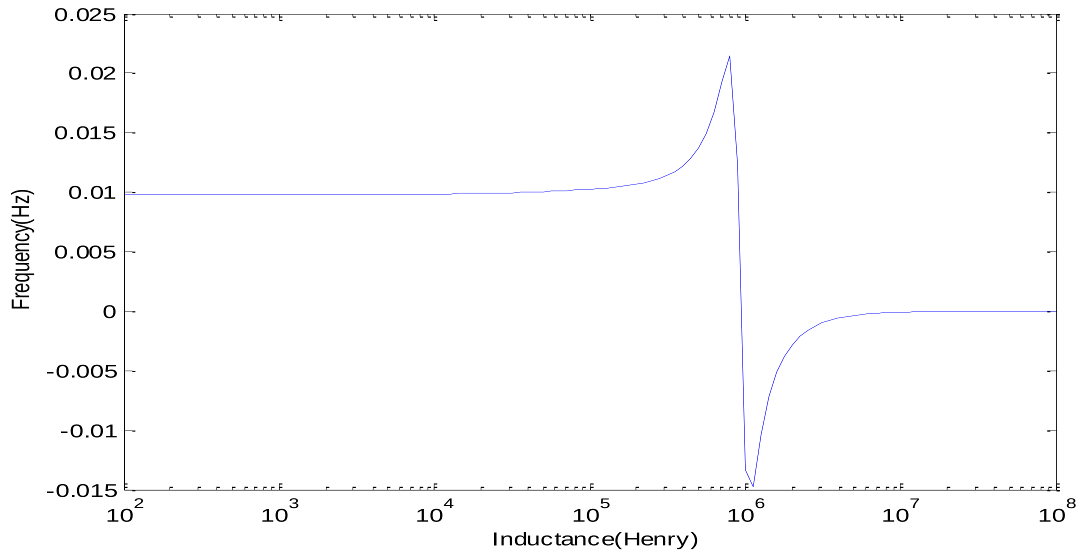

Fig 3.21 Frequency response of the simulated inductor

The floating inductor is simulated in PSPICE where the value of the $R_1 = 10K\Omega$, g_m =1mS and C=1nF .

The workability of the grounded inductor shown in Fig 3.19 has been verified by realizing an active resonant circuit given below in Fig 3.22. The inductor 'L' has been replaced by the simulated inductor.

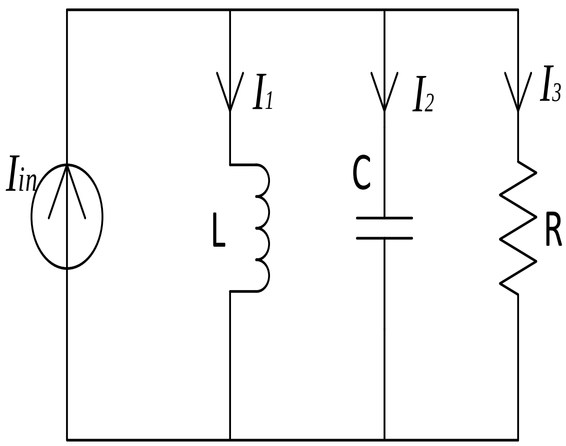

Fig 3.22 Second order RLC circuit using a grounded inductor

From the circuit diagram,

$$\frac{I_1}{I_{in}} = \frac{R(\frac{1}{sc})}{(RsL+\frac{R}{sc}+\frac{L}{sc})} \tag{3.37}$$

$$\frac{I_1}{I_{in}} = \frac{\frac{1}{LC}}{(s^2+\frac{s}{RC}+\frac{1}{LC})} \tag{3.38}$$

For the above transfer function the frequency response is shown in the following figure.

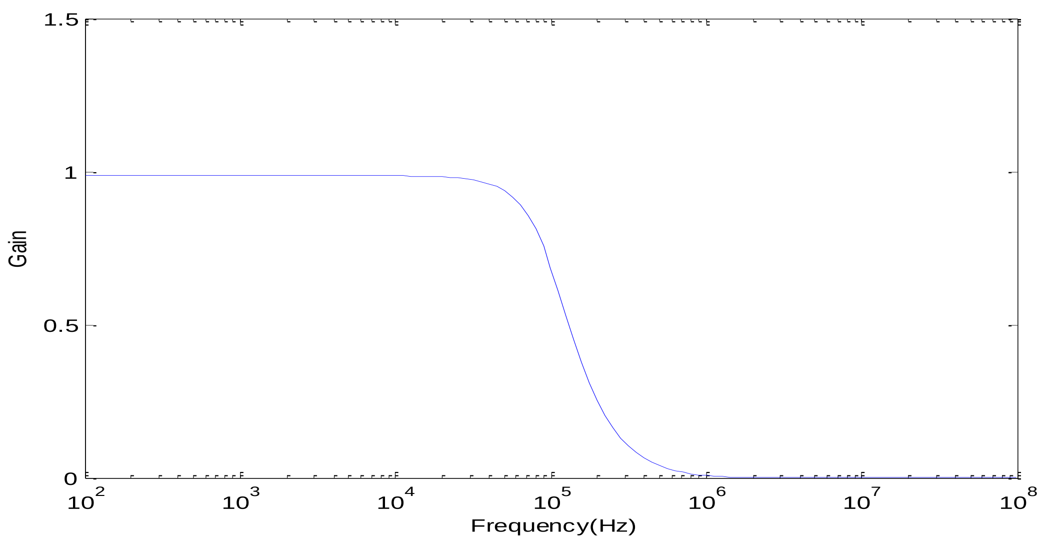

Fig 3.23 Frequency response of second order low pass transfer function

The frequency response of the transfer function in equation (3.38) is shown in the above figure. It is designed for cut-off frequency of 100KHZ. The value of R=1KΩ,C=1nF,L=2.5mH.

From the circuit in the figure 3.22 the transfer function for the current through resistor is given by

$$\frac{I_3}{I_{in}} = \frac{\frac{sL}{sc}}{sLR+\frac{R}{sc}+\frac{L}{C}} \tag{3.39}$$

$$\frac{I_3}{I_{in}} = \frac{\frac{s}{Rc}}{s^2+\frac{1}{Lc}+\frac{s}{Rc}} \tag{3.40}$$

For the above transfer function the frequency response is given in the figure below.

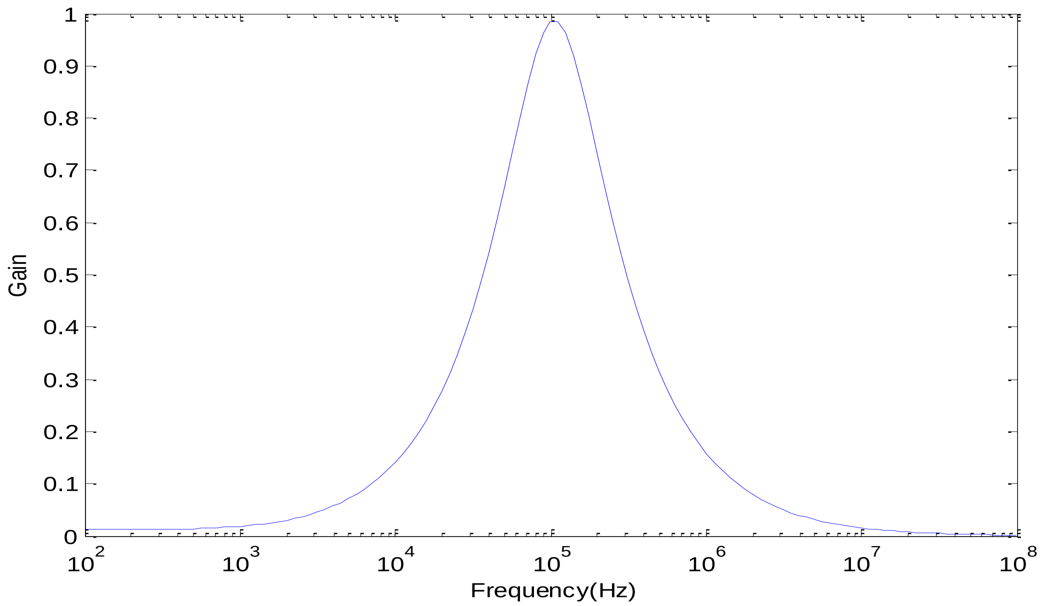

Fig 3.24 Frequency response of band pass transfer function

The frequency response of the transfer function in (3.40) for the designed centre frequency of 100KHz. From the simulation results it is 103KHz.

From the figure 3.7,

$$\frac{I_2}{I_{in}} = \frac{sLR}{sLR+\frac{R}{sC}+\frac{L}{C}} \tag{3.41}$$

$$\frac{I_2}{I_{in}} = \frac{s^2}{s^2+\frac{s}{RC}+\frac{1}{LC}} \tag{3.42}$$

The frequency response for the above transfer function is shown below.

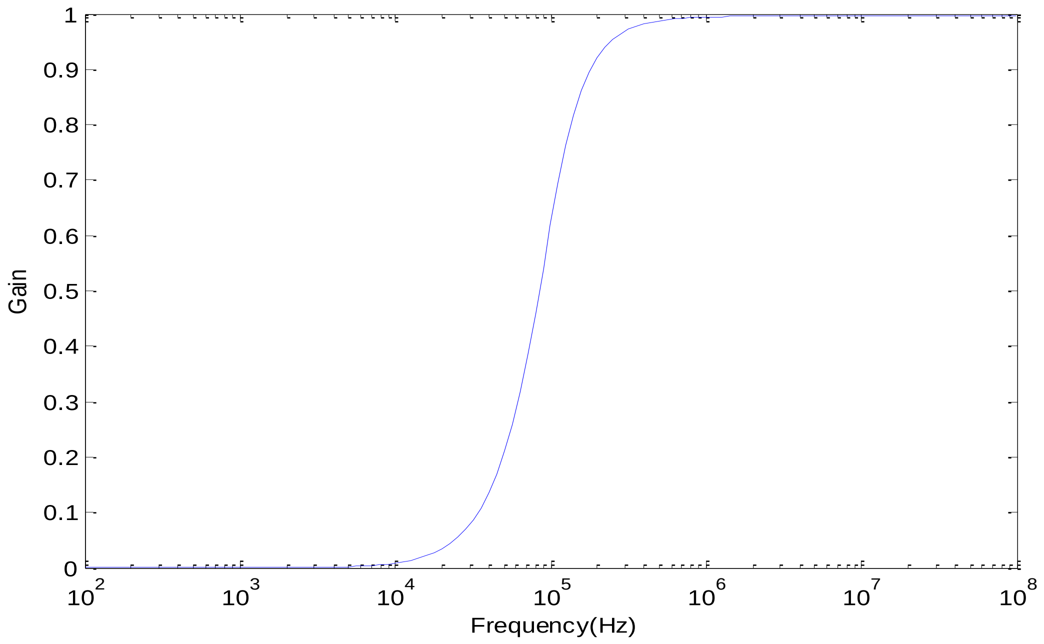

Fig 3.25 Frequency response of high pass transfer function

The frequency response for the transfer function in equation(3.42) using grounded inductor is shown in the fig 3.25. High pass filter is designed for the cut-off frequency of 100KHZ whereas from the PSPICE simulation the result of the cut-off frequency is 105KHZ.

3.8 Conclusion

In this chapter grounded inductor and floating inductor are implemented using CBTA and are simulated using PSPICE simulation software. The implemented grounded inductor is used in an RLC circuit to realise 2^{nd} order low pass filter, band pass filter and high pass filter.

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CHAPTER 4
LADDER FILTER REALIZATION USING CBTA

4.1 Introduction

In the previous chapter we had presented the realization of grounded as well as floating inductors using active building blocks of recent origin including CBTA.

In the present chapter we have realized LC ladder filters using element replacement technique. Using replacement technique, we realized 5^{th} order lowpass and highpass Butterworth filters. We also present a novel 4^{th} order Butterworth low pass filter realized by using a synthesis technique described in [2].

4.2 Analog filters

Basic electric filters were developed by both Wagner and Campbell independently in the early 20^{th} century. Since then filter theory, implementation methods have been evolved to a high degree of perfection. Implementation of active filter, a filter which uses gain, became possible with invention of vacuum tube, the development of feedback theory by Bode, Black and others. In the present days the wide use of high quality low cost discrete analog active filters is because of the development of inexpensive monolithic operational amplifier(opamp) by Widlar in1960's. In the recent time the practice to accommodate even more complicated complete systems on a monolithic integrated circuit (IC), filter designers felt pressure to devise techniques that allow the integration of analog filters onto the IC along with digital circuitry. The solution was found to be switched capacitors for low to medium frequencies. The use of transconductance amplifiers led to integrated filters at high range of frequencies.

Analog active filters use gain and capacitors. In integrated active filters we obtain gain by making us of transconductance amplifiers or operational amplifiers or in general any one of the four types of controlled sources. To be able to decide which components to use, and whether to use an active filter in preference to a filter consisting of passive components, we should take various factors into account such as:

1) The technology desired for the implementation of system.
2) The range of DC supply available for active devices and power consumption.
3) Range of frequencies over which it is to be operated.

4) Cost.
5) Stability and sensitivity to parameter changes.
6) Size and weight of the implemented circuit.
7) Effect of noise.

4.3 LC ladder filter design

The LC ladders have an advantage over active filters in terms of their sensitivity to component tolerances. Because of the sensitivity to component values that characterizes the doubly terminated LC ladders, these circuits are commonly used in filter applications. LC ladder is used as a model for circuits that use active elements to simulate inductors and other elements. We are interested in lossless ladders for various reasons:

1) Although the design of LC filters has its roots in antiquity, lossless ladders remain widely used to this day for high frequency applications or when no power is available to drive the active devices.
2) LC ladder filters develop prototype models that are simulated by active circuits both with discrete components and in fully integrated form on an integrated circuit chip. The aim is to develop the active circuits in such a way that the simulation inherits the excellent sensitivity properties of lossless passive ladders.
3) Finally if we succeed in developing an active simulation of the passive ladder, we will be able to make use of the huge volume of design information and tables that are available for LC ladders.

In the LC ladders the signal is supplied to the ladder by a resistive source and the load is resistive as well, the ladder is said to be doubly terminated. The low sensitivity property we are interested in valid for doubly terminated ladders. Sensitivities can be shown to worse when either or both terminations are absent for eg: source resistance=0 and/or load resistance=infinite. We therefore be concerned only with ladders working between two resistors.

4.4 Synthesis procedure

In the doubly terminated circuit shown in the figure 4.1,we represented the current from the source I_1 and its reference direction and Z_{in} as the input impedance of the RLC circuit made up of the lossless ladder terminated by R_l. Here assumption is that the circuit is in sinusoidal steady state. Writing the input impedance in terms of real and imaginary components.

$$Z_{in} = R_{in} + jX_{in}$$

and the input current is $I_1 = \frac{V_{AC}}{R_s+Z_{in}}$

Since the ladder circuit is lossless, we can equate the average power into the circuit, P_1 to that of average power in the load.

$$P_1 = R_{in}|I_1(j\omega)|^2 = \frac{|V_2(j\omega)|^2}{R_l}$$

Substituting the value of I_1 into this equation gives us

$$\frac{R_{in}|V_{AC}(j\omega)|^2}{|R_s + Z_{in}|^2} = \frac{|V_2(j\omega)|^2}{R_l}$$

From the above equation we can write

$$\left|\frac{V_2(j\omega)}{V_{AC}(j\omega)}\right|^2 = |T(j\omega)|^2 = \frac{R_l R_{in}}{|R_s + Z_{in}|^2}$$

For the LC ladder filter we know that

$$|H(j\omega)|^2 = \frac{P_2}{P_{1max}} = \frac{4R_s}{R_l}\left|\frac{V_2(j\omega)}{V_{AC}(j\omega)}\right|^2$$

From the above two equations

$$|H(j\omega)|^2 = \frac{4R_s}{R_l}\left|\frac{V_2(j\omega)}{V_{AC}(j\omega)}\right|^2 = \frac{4R_s R_{in}}{|R_s + Z_{in}|^2} \leq 1$$

$$|H(j\omega)|^2 = 1 - \frac{|R_s - Z_{in}|^2}{|R_s + Z_{in}|^2} = 1 - |\rho(j\omega)|^2$$

Where $\rho(s)$ is known as reflection coefficient. $\rho(s)$ is a measure of how well R_s and Z_{in} are matched. We have always $|\rho(j\omega)|^2 \leq 1$ and for perfect matching $\rho(s) = 0$. $\rho(s)$ can be written as

$$\rho(s) = \pm\frac{R_s - Z_{in}(s)}{R_s + Z_{in}(s)}$$

$$Z_{in} = R_s \frac{1+\rho(s)}{1-\rho(s)} \quad \text{or}$$

$$Z_{in} = R_s \frac{1-\rho(s)}{1+\rho(s)}$$

Since ρ is determined by prescribed transfer function H, we can determine a lossless circuit terminated in a resistor R_l from a specified Z_{in}.

We get the values of the L and C components for the required order. The order of the circuit can be found depending on the α_{min}, α_{max} and ω_p and ω_s. Depending on the order we select the values of the L and C components from the predetermined tables mentioned in[1] for $\omega = 1rad/sec$. This values of the L and C are scaled according to the required value of cut-off frequency, source resistance and load resistance. and For the required cut-off frequency we need to scale the values of the inductor and capacitor components. With these values of L and C we realize the filter for the required cut-off frequency.

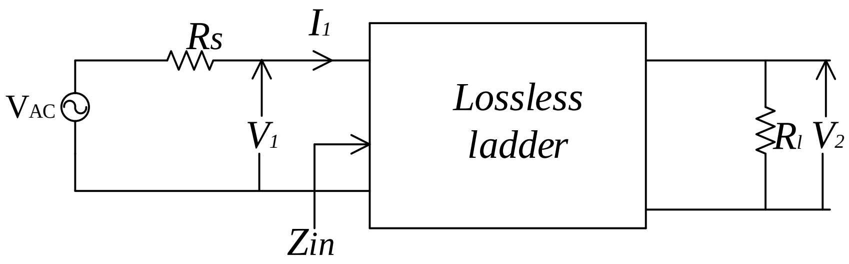


Fig 4.1 Doubly terminated lossless ladder filter

4.5 Fifth order LC ladder filter using CBTA

The LC ladder (doubly terminated) representing a fifth order lowpass filter(Butterworth) at 1rad/sec is given in the table in[1] and is shown in the fig 4.2 where R_1=1Ω, $C_1 = 0.618F$, $L_1 = 1.618H$, $C_4 = 2F$, L_2 =1.618H, C_5 =0.618F, R_4=1Ω. The values of the L and C components for the above fifth order LC ladder filter are denormalized using frequency scaling and magnitude scaling depending on source, load resistance and cut-off frequency. The specifications in the present case are R_s=10KΩ, R_l=10KΩ and $\omega_c = 2.9Mrad/sec$ (for 460KHz).

The formulas for conversion of component values from standard frequency of 1rad/sec to required frequency is given by $L_{req}=\frac{L_1 R}{\omega_c}$; $C_{req} = \frac{C}{R\omega_c}$

Finally replacing the floating inductors $L_1\ and\ L_2$ by the CBTA based floating inductor presented in chapter3(Fig 3.19) we get the active fifth order lowpass Butterworth filter as shown in Fig 4.3.

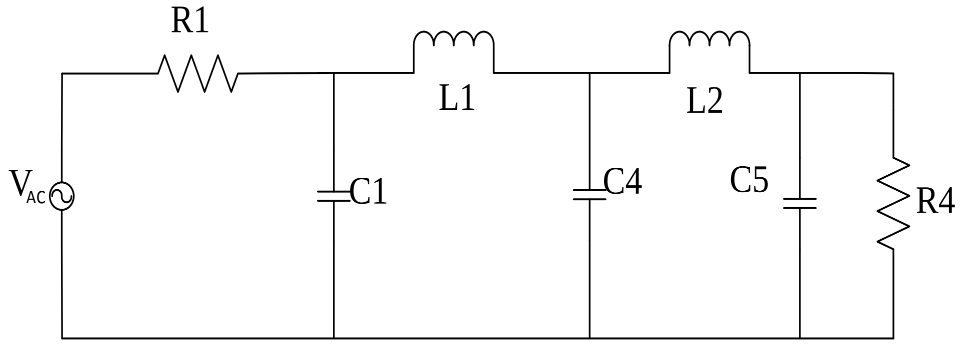


Fig 4.2 Fifth order LC ladder lowpass filter prototype

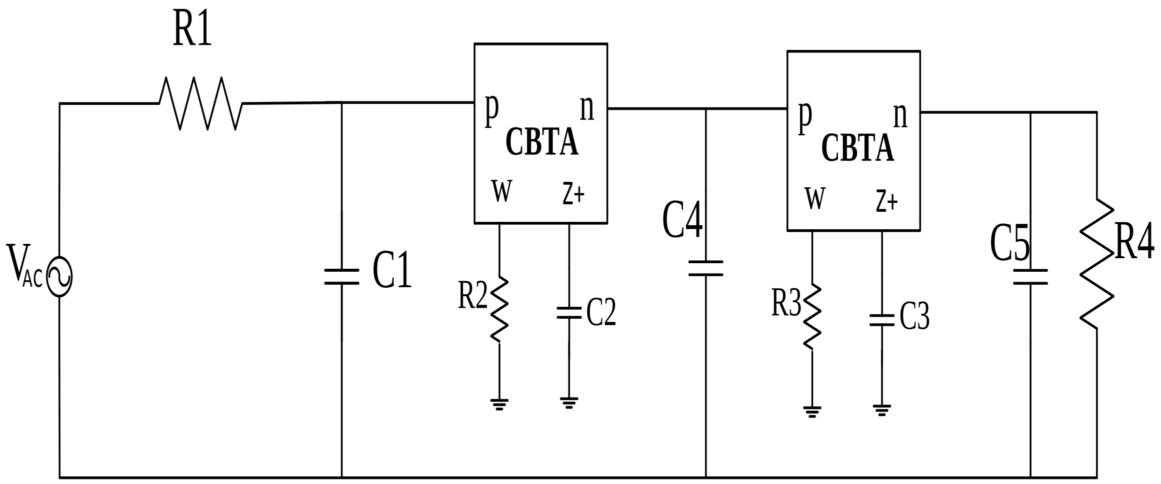


Fig 4.3 Fifth order filter using CBTA

The values of $R_1 = 10K\Omega$, $C_1 = 21.3pF, C_4 = 69.19pF, C_5 = 21.3pF$, $L_1 = 5.56mH$, $L_1 = 5.56mH$, $R_1 = R_3 = 5.56K\Omega, C_1 = C_3 = 1nF$. The simulation results are shown in the following graphs

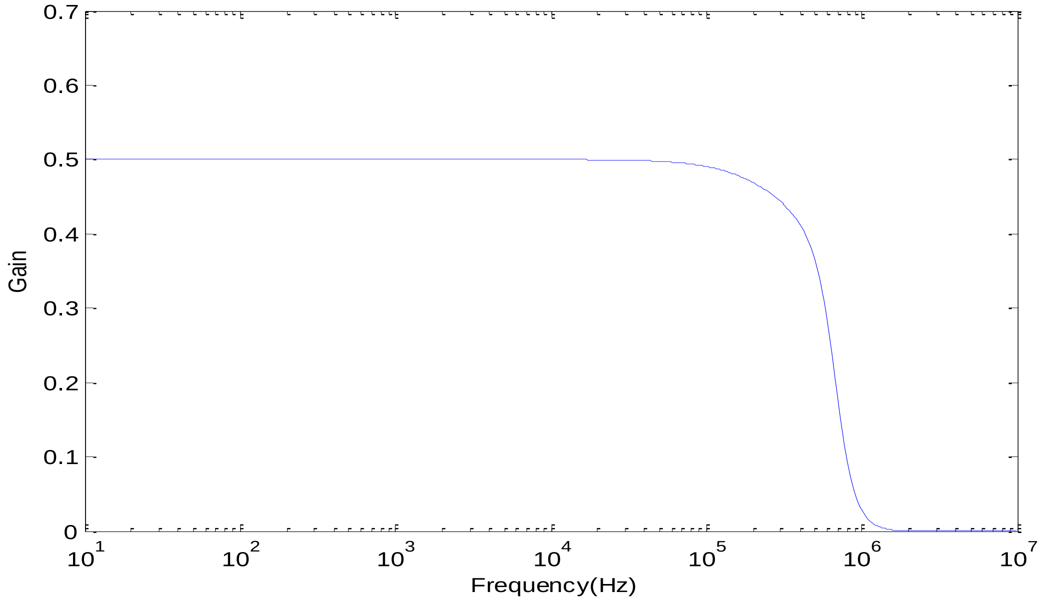


Fig 4.4 Frequency response characteristics of 5^{th} *order lowpass filter*

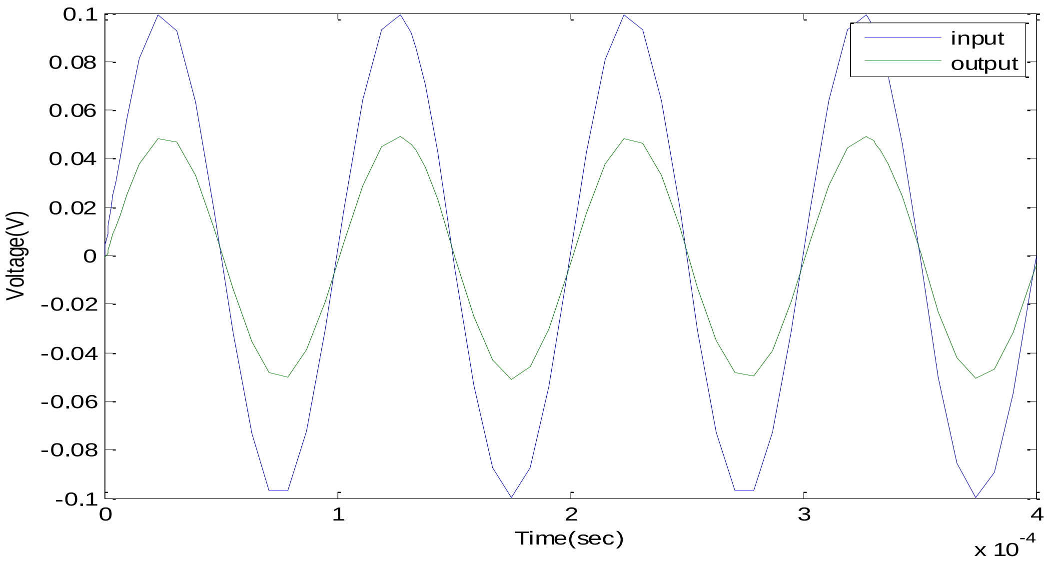


Fig 4.5 Time response of 5^{th} *order lowpass filter*

4.6 Low pass to high pass transformation

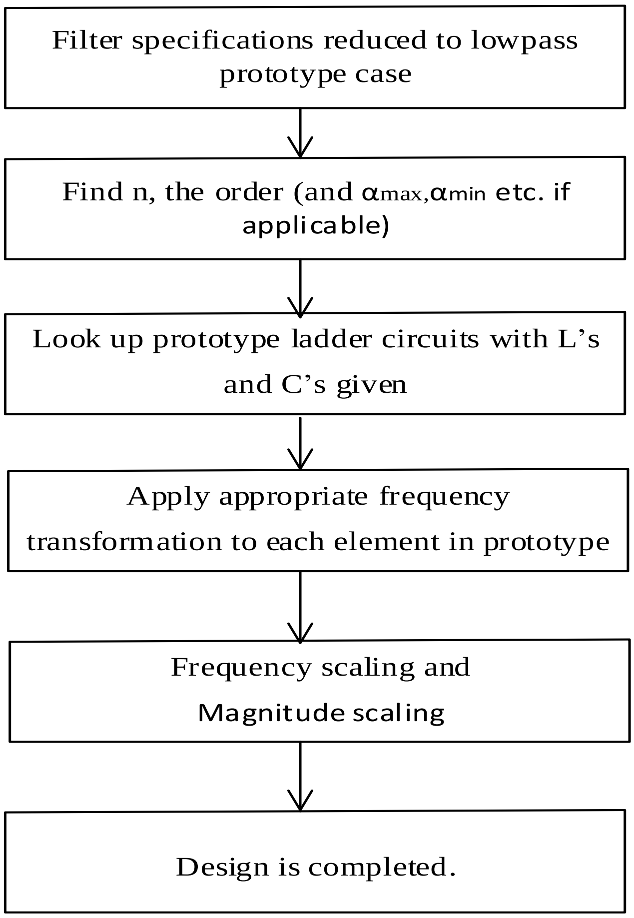
In order to design a higher order LC ladder highpass filter it is required to find the specifications of the corresponding prototype low pass filter. Depending on the value of $\alpha_{min}, \alpha_{max}$ find the order of the filter.

$$n = \frac{\log[\frac{10^{.1\alpha_{min}} - 1}{10^{.1\alpha_{max}} - 1}]}{2log\omega_s}$$

After finding the order find out values of L and C components for the corresponding order from the table in[1]. Find the required values of the inductors and capacitors by frequency scaling and magnitude scaling. The formulae for the L and C components are given by

$$C_{HP} = \frac{1}{L_{LP} R \omega_c},$$

$$L_{HP} = \frac{R}{C_{LP} \omega_c}$$



The LC ladder (doubly terminated) representing a fifth order highpass filter(Butterworth) at 1rad/sec is given in the table in[1] and is shown in the fig 4.6 where R_1=1Ω, $C_1 = 1.618F$, $L_2 = 0.618H$, $C_3 = .5F$, $L_4 = .618H$, $C_5 = 1.618F$, R_4=1Ω. The values of the L and C components for the above fifth order LC ladder filter are denormalized using frequency scaling and magnitude scaling depending on source, load resistance and cut-off frequency. The specifications in the present case are R_s=10KΩ, R_l=10KΩ and $\omega_c = 630Krad/sec$ (for

100KHz). Replacing the grounded inductor by the CBTA based grounded inductor realized in the chapter 3(Fig 3.16) we get the active fifth order highpass Butterworth filter as shown in Fig 4.6.

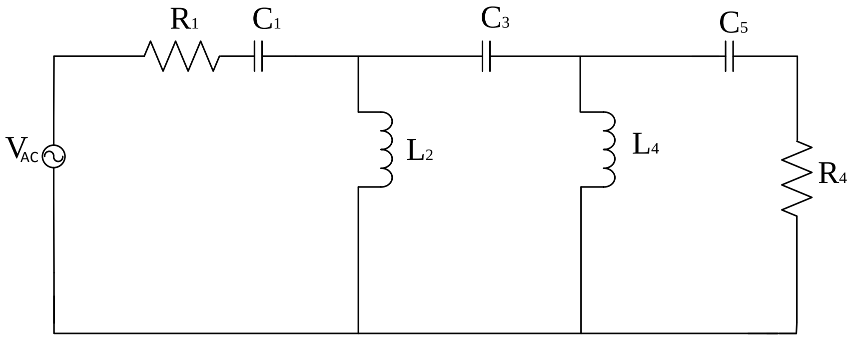


Fig 4.6 Prototype 5^{th} *order high pass LC ladder filter*

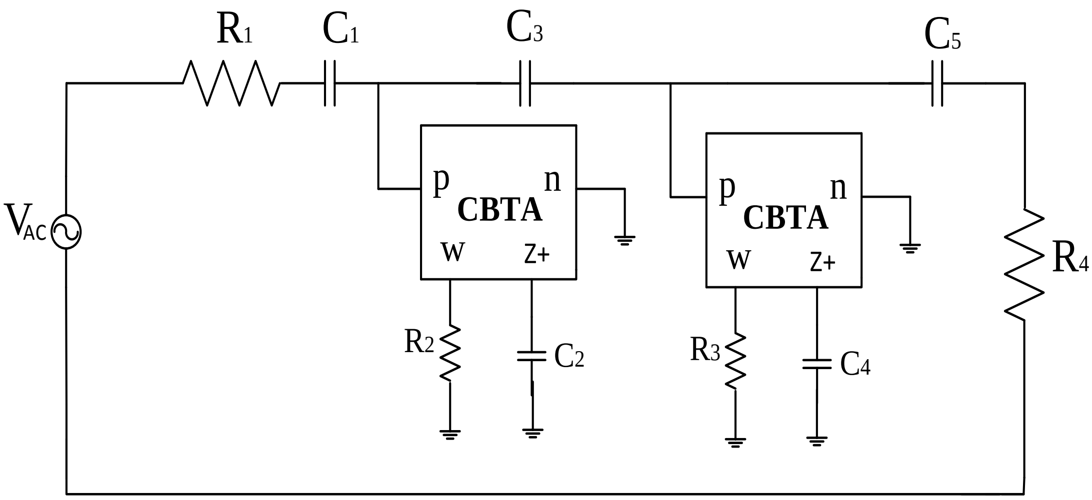


Fig 4.7 5^{th} *order high pass filter using CBTA*

The values of $R_1 = 10K\Omega$, $C_1 = 256pF, C_3 = 79.36pF, C_5 = 256pF$, $R_4 = 10K\Omega$, $R_2 = 9.8K\Omega, R_3 = 9.8K\Omega$, $C_2 = 1nF$, $C_4 = 1nF$. The simulation results are shown in the following graphs

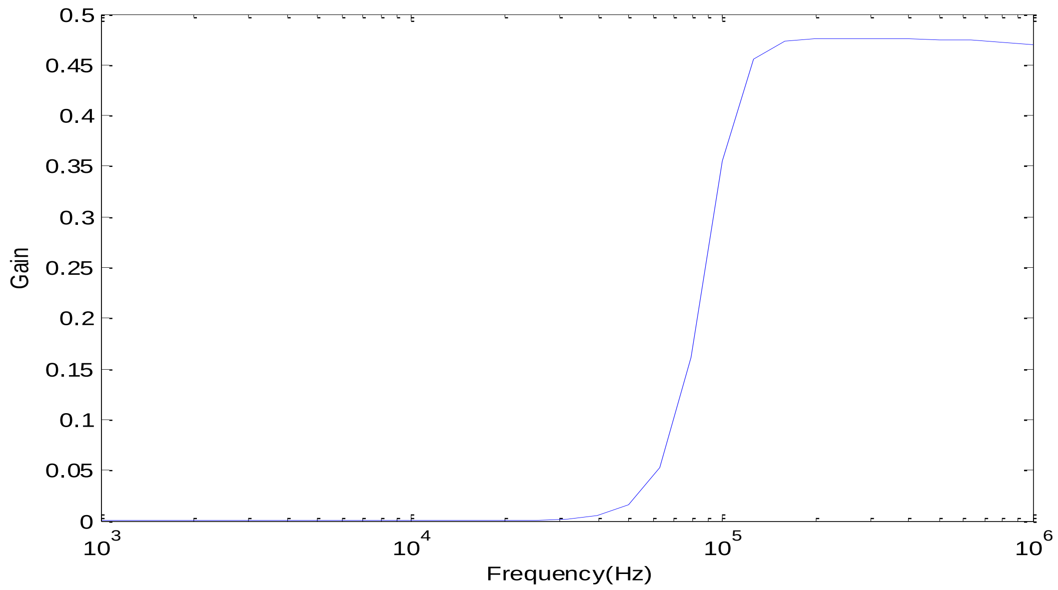


Fig 4.8 Frequency response of 5^{th} order filter using CBTA

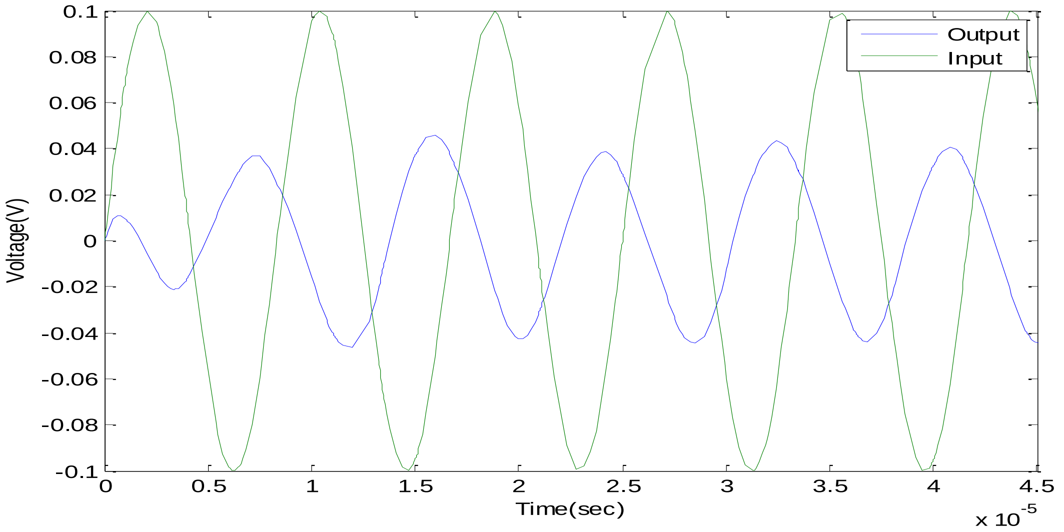


Fig 4.9 Time response of 5^{th} order highpass filter using CBTA

4.7 4^{th} order Active filter design using CBTA

We now present the realization of a fourth order all pole transfer function based on the work presented in [2]. The general all pole current transfer function is given in [2] using CBTA. From this, the circuit for 4^{th} order current transfer function is shown as below in fig 4.10

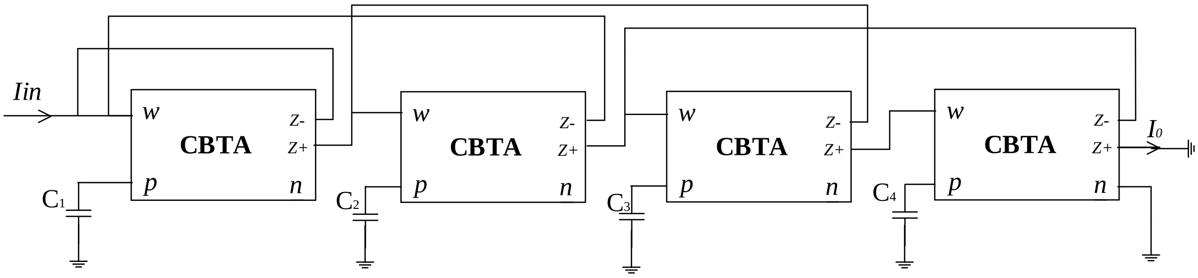


Fig 4.10 4^{th} *order active Butterworth lowpass filter*

For the general n^{th} order circuit, due to the capacitors at terminal p,

$$V_{pk} = -Z_k I_{wk},\ Z_k = \frac{1}{C_k s},\ \text{for } k=1,2,\ldots n \qquad (4.1)$$

Writing the equations for the current at terminal w_k,

$$I_{wk} = -I_{in} + gV_{pk} + gV_{p(k+1)},\ \text{for } k=1$$

$$= -gV_{p(k-1)} + gV_{p(k+1)},\ \text{for } k=2,3,\ldots n-1$$

$$= -gV_{p(k-1)},\ \text{for } k=n \qquad (4.2)$$

The output is given by

$$I_o = -gZ_n I_{wn} \qquad (4.3)$$

Substituting the equation (4.1) in (4.2), writing it in matrix form and solving the matrix gives the solution for I_o.

The solution for I_{wn} and hence I_o can be obtained by using numerical algebra techniques. The current transfer function is given by

$$\frac{I_o}{I_{in}} = \frac{g^n Z_1 Z_2 \ldots\ldots\ldots Z_n}{\Delta_n} \qquad (4.4)$$

where the determinant of the coefficient matrix in equation and is given by

$$\Delta_n = 1 + gZ_1 + g^2 Z_1 Z_2 + \ldots\ldots + g^n Z_1 Z_2 \ldots . Z_n \qquad (4.5)$$

New formulas are used for design purpose by normalizing each capacitor value by g

$$gZ_k = \frac{g}{c_k s} = \frac{1}{\frac{c_k s}{g}} = \frac{1}{C_k s} \qquad (4.6)$$

Multiplying numerator and denominator in equation (4.4) by $c_n c_{n-1} \ldots \ldots c_1 s^n$, the transfer function becomes

$$H(s) = \frac{I_o}{I_{in}} = \frac{1}{Q(s)} = \frac{1}{q_n s^n + q_{n-1}s^{n-1} + \cdots \ldots + q_1 s + q_o} \quad (4.7)$$

Where $q_n = c_n c_{n-1} \ldots \ldots . c_1$, n≥ 1

$q_{n-1} = c_n c_{n-1} \ldots \ldots . c_2$, n≥ 2,

$q_1 = c_n + c_{n-2} + \cdots \ldots . + c_1$, for odd n≥ 1

$= c_n + c_{n-2} + \cdots \ldots . + c_2$, for even n≥ 2 (4.8)

The recurrence formula for the denominator polynomial is

$$Q_o(s) = 1 \quad (4.9)$$

$$Q_1(s) = 1 + c_1 s \quad (4.10)$$

$Q_k(s) = c_k s Q_{k-1} + Q_{k-2}$, for k=2,3,..n (4.11)

The above recurrence formula is main tool to fix the values of the passive components(capacitors).

4.7.1 Synthesis procedure

From the values of the coefficients of denominator polynomial it is possible to determine the normalised values of capacitances $c_1, c_2, .. c_n$. For first order case, i.e, n=1 from equation (4.10)

$$c_1 = q_1 \quad (4.12)$$

By comparing the denominator of equation (4.7) with the polynomial obtained from recurrence formula the value of capacitors for n≥2 can be obtained as

for n=2 $c_1 = \frac{q_2}{q_1}$, $c_2 = q_1$ (4.13)

for n=3 $c_1 = \frac{q_3}{q_2}$, $c_2 = \frac{q_2{}^2}{q_1 q_2 - q_3}$, $c_3 = \frac{q_1 q_2 - q_3}{q_2} = q_1 - c_1$ (4.14)

for n=5

$c_1 = \frac{q_4}{q_3}$, $c_2 = \frac{q_3}{q_2 - c_1 q_1}$, $c_3 = \frac{q_3}{c_2(q_1 - c_2)}$, $c_4 = q_1 - c_2$ (4.15)

$$C_n = \frac{g_m c_n}{\omega_c} \quad (4.16)$$

Consider a 4^{th} order Butterworth filter transfer function as

$$\frac{I_o}{I_{in}} = \frac{1}{s^4+2.61312s^3+3.414213s^3+3.4142136s^2+2.61312s+1} \tag{4.17}$$

The normalised component value of the capacitances for the above transfer function from equation (4.17) is $c_1 = 0.38268F$,$c_2 = 1.082F, c_3 = 1.577F, c_4 = 1.5312F$ and the actual values of the components for $g_m = 1$mS, $\omega_c = 1Mrad/sec$ from equation (4.16) is $C_1 = 0.38268nF, C_2$=1.082nF,$C_3 = 1.577nF, C_4 = 1.5312nF$.

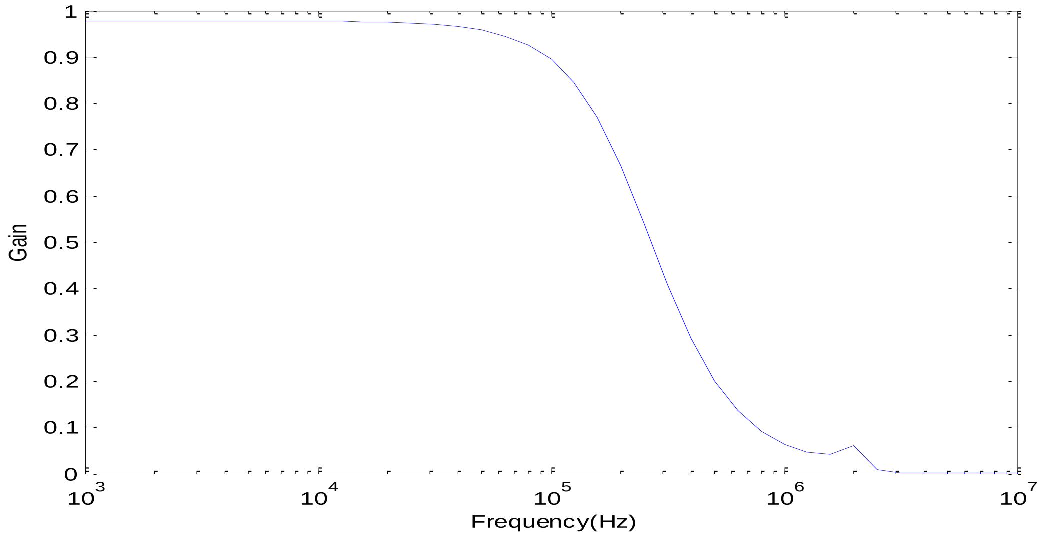


Fig 4.11 Frequency response of 4^{th} order lowpass active filter using CBTA

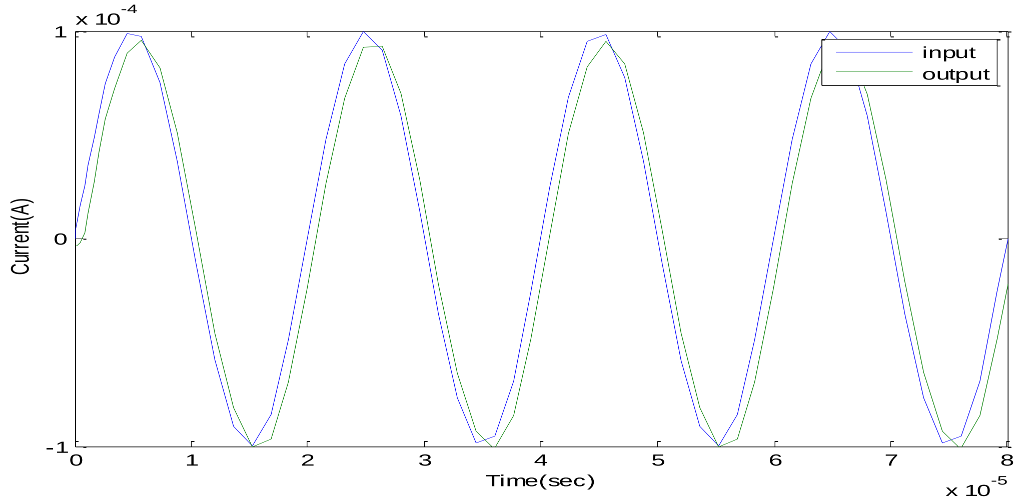


Fig 4.12 Time response of 4^{th} order active lowpass filter using CBTA

4.8 Conclusion:

In this chapter we described the about LC ladder filters. LC ladder filters have the advantages of lossless and sensitivity. In this chapter we discussed the procedure of finding the component values from the Butterworth table corresponding to required cut-off frequency. The components of high pass filters can be found out by appropriate frequency transformation techniques. The grounded and floating inductors realized in the previous chapter are used in the above ladder filters. Apart from the ladder filters, lowpass filter using CBTA is realized in this chapter.

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CHAPTER 5

SUMMARY AND FUTURE SCOPE

SUMMARY

In this dissertation work we introduced an active building block CBTA which was implemented in [1]. In chapter 1 we described about various active devices in detail. A brief comparison of voltage and current modes of signal processing is given in the chapter1. In the chapter 2 of this thesis we presented the active block CBTA. This is implemented using bipolar array BJTs and is simulated using PSPICE simulation software. In this chapter we presented some of the basic applications using CBTA such as inverting amplifier, non-inverting amplifier, first order filters etc., We presented the various characteristics of CBTA in this chapter.

In chapter 3, we implemented grounded inductor and floating inductor using one CBTA, one capacitor and one resistor. Further the implemented grounded inductor is used in second order RLC circuit to realise low pass filter, band pass filter and high pass filter.

In chapter 4, we implemented higher order filters using LC ladder structure. In the LC ladder we replaced the floating or grounded inductors with the inductors realized in chapter 3 using CBTA. Fourth order active filter using the synthesis procedure presented in one of the references is also realized in this chapter. The LC ladder filters are advantageous with respect to sensitivity.

FUTURE SCOPE

In the present work we discussed about the active block CBTA and its basic applications like inverting and non-inverting amplifier. In this we also implemented grounded inductor, floating inductor, different types of current mode filters using this CBTA. This work can be extended to other applications like oscillators, KHN Biquad filter etc., There is also scope for implementation of the aforesaid applications using other active elements.

Appendix

The transistor model of PR100N and NR100N of the bipolar arrays ALA400 are used in the BJT implementation shown in figure 2.3. These transistor models operate at a voltage of DC supply ±2.5V.

The characteristics of the NR100N and PR100N bipolar arrays are given below

.MODEL NR100N NPN (RB=524.6 IRB=0 RBM=25 RC=50 RE=1 IS=121E–18 EG=1.206 XTI=2 XTB=1.538 BF=137.5 IKF=6.974E–3
+ NF=1 VAF=159.4 ISE=36E–16 NE=1.713 BR=0.7258 IKR=2.198E–3 NR=1 VAR=10.73 ISC=0 NC=2 TF=0.425E–9 TR=0.425E–8
+ CJE=0.214E–12 VJE=0.5 MJE=0.28 CJC=0.983E–13 VJC=0.5 MJC=0.3 XCJC=0.034 CJS=0.913E–1 VJS=0.64 MJS=0.4 FC=0.5)

.MODEL PR100N PNP (RB=327 IRB=0 RBM=24.55 RC=50 RE=3 IS=73.5E–18 EG=1.206 XTI=1.7 XTB=1.866 BF=110.0 IKF=12.359E–3
+ NF=1 VAF=51.8 ISE=25.1E–16 NE=1.650 BR=0.4745 IKR=6.478E–3 NR=1 VAR=9.96 ISC=0 NC=2 TF=0.610E–9 TR=0.610E–8
+ CJE=0.180E–12 VJE=0.5 MJE=0.28 CJC=0.164E–12 VJC=0.8 MJC=0.4 XCJC=0.037 CJS=1.03E–12 VJS=0.55 MJS=0.35 FC=0.5)