

SIGNAL PROCESSING CIRCUITS USING OPERATIONAL TRANSCONDUCTANCE AMPLIFIERS

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Abstract- A number of techniques and circuits are available in literature for designing various signal processing circuits suitable for VLSI implementation. Some of the approaches and circuits widely investigated so far are g_m -C circuits, switched capacitor circuits. In principle, all of them can be employed to devise fully integratable implementation in BIPOLAR, CMOS, and Bi-CMOS technology. Recently some work has been done on employing BJT and MOSFET based current mirrors as alternating building blocks, in contrast to more complex building blocks employed in the above mentioned approaches. This paper work has investigated the state of the art of this technique and has explored the various possible options available. A critical examination based upon the rigorous analysis and/or PSPICE simulation is aimed and possible attempts will be made to search for a new design method for circuit configuration. In this paper attention was focused on the realization of voltage-mode building blocks such as voltage adders and voltage integrators (lossy and lossless) which forms the major constituent for implementing active filters. As an example to demonstrate the realization procedure, voltage-mode second order filters and TOW THOMAS Biquad obtained by cascading lossy and lossless voltage integrators and KHN Biquad filter cascading two lossy integrators.

All the realized circuits were tested using SPICE and the results thus obtained were in accordance with the theoretical values.

Index Terms- OTA, DVCCS

I. INTRODUCTION

Operational Transconductance Amplifiers (OTAs) have become available as an off-the-shelf item in the monolithic IC form. It is differential voltage controlled current source (DVCCS), i.e. it produces output current proportional to the differential input voltage, and has an extra control terminal for controlling its transconductance. Besides having attractive realization features offered by an operational amplifier (OA), the OTA additionally provides

excellent electronic tunability by virtue of its highly linear transconductance versus bias current relationship, for over four decades. This has given great impetus to active circuit realizations using OTAs instead of OAs, particularly, in applications where electronic tunability forms an important consideration

In modern communication and instrumentation system, active networks are extensively being used in the realization of filters, oscillators, voltage controlled oscillators, phase shift oscillators, etc. Among them active RC ones using OAs as the active device have gained great prominence due to their reliable, stable and low sensitivity performance at reasonable cost. In addition, they (active RC circuits) enjoy good prospects for integration. Over the last few decades, it has been shown that the OTAs, with their excellent electronic tunability, can conveniently realize electronically tunable filters and oscillators. This feature, along with the availability of OTAs, has made them a strong rival to the OA, particularly in applications where electronic tunability is considered an important criterion in the filter design. In some applications, such as, music synthesis, automatic control, speech synthesis, independent electronic tuning of the filter parameters is needed. The use of programmable integrators (PIs), based on OTAs, instead of analogue voltage multipliers and fixed integrators has many advantages. The transconductance versus amplifier bias-current relationship of an OTA is highly linear and has been so far over four decades. Hence, electronic control of filter parameters, such as, the pole-frequency, the pole-Q and the absolute bandwidth, are conveniently possible through the bias-current over many decades of tuning range.

1.1 ADVANTAGES:-

The electronically tunable active filters, using monolithic integrated OTAs, present the following advantages over those employing analogue voltage multipliers and fixed integrators:

- (i) Programmable integrators based on OTA, are relatively less expensive than the commercially available analogue voltage multipliers and fixed integrators.
- (ii) The OTA realizes an ideal integrator of sufficiently high frequency and a pole at the origin, which is not possible with fixed integrators realized by OAs.
- (iii) The dynamic range of OTA-based programmable integrator is much larger than analogue voltage multiplier and fixed integrator. Hence, electronic control of filter parameters is possible over several decades.
- (iv) The signal level at the output of each OTA-based programmable integrator in the filter circuit is independent of the tuning current. This means that the distortion and noise of the circuit are reasonably independent of tuning. Whereas, in the case of analogue voltage multipliers and fixed integrators, the signal to noise ratio decreases with the increase in the tuning frequency.

The above stated advantages and flexibilities associated with an OTA, along with their availability in monolithic IC form, motivate us to explore its Utility in the development of electronic circuits, particularly for the current mode filters and oscillator circuits.

1.2 LIMITATIONS:-

The main limitation of circuits realized with OTAs lies in the temperature dependence of their transconductance. As a result, filter parameter sensitivity increases to a considerable extent. It is, therefore, necessary to use suitable temperature compensation circuits in conjunction with the integrated OTAs, for reliable circuit operation over a wide range of temperature variations.

1.3 OTA:-

The salient features of OTA are similar to conventional OAs, but differ sufficiently to justify an explanation of their characteristics. This class of IC has not only the usual differential input and single output terminals, but it also has

an extra control terminal through which its transconductance (g_m) can be linearly controlled over a wide range with the amplifier bias current (I_b). This feature is mainly responsible for the inherent tunability associated with the OTA and provides greater flexibility to the circuit designer.

The characteristics of an ideal OTA are similar to those of an ideal OA except that an OTA has an extremely high output impedance (ideally infinite), rather than zero. Because of this, the output signal is given in terms of current, which is proportional to the differential input voltage. Thus the transfer characteristic of an OTA is best described in terms of transconductance rather than voltage gain. OTA is a monolithic, direct coupled, differential voltage controlled current source (DVCCS). Feedback is added to control its overall performance. When operated with a suitable load with provision for feedback, the OTAs are very well suited for a wide variety of applications.

The symbolic representation of OTA is shown in Fig 1.1. The basic equivalent circuits of an ideal and non-ideal OTA are given in Fig 1.2(a) and (b) respectively. The voltages V_1 and V_2 are applied to the inverting and non-inverting terminals respectively. The output signal is a current which is proportional to the transconductance of the OTA established by the amplifier bias current I_b . The OTA can either source or sink current at the output terminals, depending upon the polarity of the input voltage. The output current of the OTA is given by.

$$I_o = g_m(V_2 - V_1)$$

where g_m is the transconductance of the OTA.

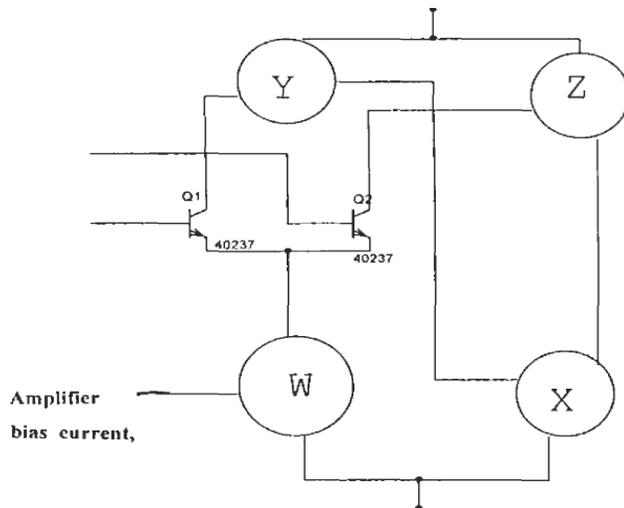


Figure 1:- Simplified Block Diagram of an OTA structure; X, Y, Z & W are the current mirrors

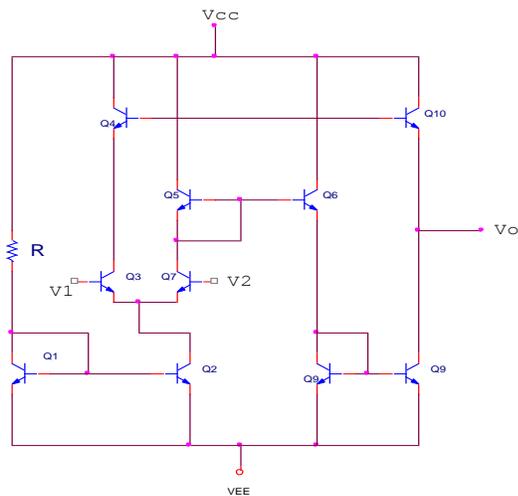


Figure 2:-Schematic diagram of OTA

II. JIE WU,S MODEL

Another non ideal model of OTA was presented in 1994 by Jie Wu, which closely resembles the model discussed above. The model is shown in Figure 2.9 and is also called a micro model of OTA. The values of R_i , C_i , R_o , and C_o are described to be $100K\Omega$, 2.6 pF , $70M\Omega$ and 3.6 pF respectively. During the project an experiment, using simulation, was performed to test the validity of this model. The input output characteristic of this model and the commercially available OTA (LM 13600) were obtained. These were found to agree remarkably. The results are shown in Fig. 1.7 and 1.8. These were tested with an input of 10 mV voltage and the transconductances of both were set at 1 mS the resemblance in the performance is evident

with minor deviation which is, of course, because of approximations.

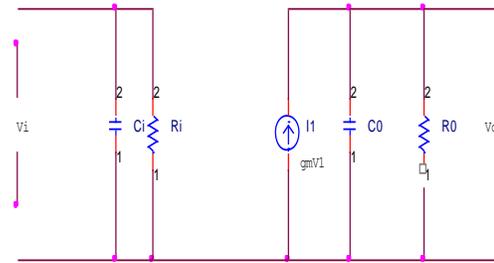


Figure 3:- JIE WU'S Model of OTA

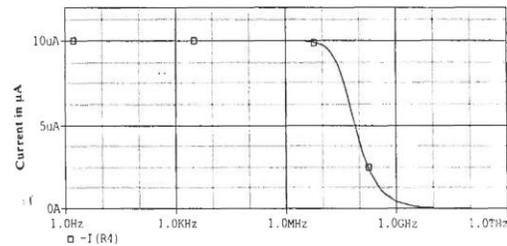


Figure 4:-Frequency Response Of JIE WU'S Macro Model Of OTA

III. BUILDING BLOCKS USED IN SIMULATION OF FILTERS

In the sub-micron era of semi-conductor technology, the minute structure of devices causes a high electric field and thus the power supply voltage is limited to a certain low value to protect the device from destruction. Current-mode signal processing (Toumazou, 1990, Angulo, 1992, and Allstot, 1992) is quite attractive from low power supply voltage operation and high frequency application point of view and is suitable for sub-micron era. In this chapter design of current-mode filters using npn transistor current mirrors and pnp transistor current sources as active loads, as reported by Fujii, 1995 which is a counterpart of the MOS realization given by Allstot, 1992. In that design, pnp transistors were only used for DC current sources which provide bias currents to each current mirror and also behave as active loads of the current mirror. The currents of these sources must match each other and also match with DC currents of each current mirror to give a proper DC bias to transistors. However the matching is sometimes difficult due to the parameter mismatch between npn and pnp transistors. In monolithic integrated circuits, it has long been prohibited to use pnp transistor for signal processing except for DC biasing purpose because of the poor characteristics of pnp transistors, especially because of their poor frequency performances. However, due to

development of semiconductor technology, pnp transistors with performances comparable to npn transistors are now available and can be used as signal processing elements. Using pnp transistors as signal processing elements, circuits can be simplified and problems resulting from difficulty of DC biasing can be avoided. The basic building blocks for the filters are current adders and current integrators consisting of current mirrors. These building blocks can easily be realized in a monolithic integrated circuit and can operate at a low DC power supply voltage of 1.5 volts. These features are desirable for single battery operated equipment such as portable audio-video equipments, personal handy phones, etc. In addition, the filters do not contain any resistors, thus simplifying the pattern of integrated circuits and thus reducing the chip area and the cost. Using integrators and adders, any kind of transfer function can be realized; therefore the method can easily be applied for wide range of filter realization. Generally, monolithic integrated filters have a difficulty on setting the filter frequency due to absolute value error of elements. In these filters, the tuning of the filter frequency can easily be achieved by adjusting the current of a single DC current source.

3.1 VOLTAGE-MODE ACTIVE FUNCTIONAL BUILDING BLOCKS USED IN FILTER SYNTHESIS:-

3.1.1 Voltage-Adder using OTA

Assuming all the OTA has an equal transconductance g_m . Then, output voltage V_o is expressed as:

$$V_o = I_o R$$

Where I_o is output current and R is external resistance.

After applying KCL at output, we have

$$I_o = I_{o1} + I_{o2}$$

Putting values of I_{o1}, I_{o2} in Eqn (2.2)

$$I_o = g_m V_1 + g_m V_2$$

Putting values of I_o in Eqn (2.1)

$$V_o = g_m R (V_1 + V_2)$$

For $g_m R = 1$ Eqn (2.3) becomes

$$V_o = (V_1 + V_2)$$

3.1.2 VOLTAGE SUBTRACTOR USING OTA:-

The output current I_o is expressed as:

$$I_o = g_m (V_{i1} - V_{i2})$$

Also

$$V_o = I_o R$$

And

$$V_o = g_m R (V_{i1} - V_{i2})$$

For $g_m R = 1$

$$\text{Then } V_o = (V_{i1} - V_{i2})$$

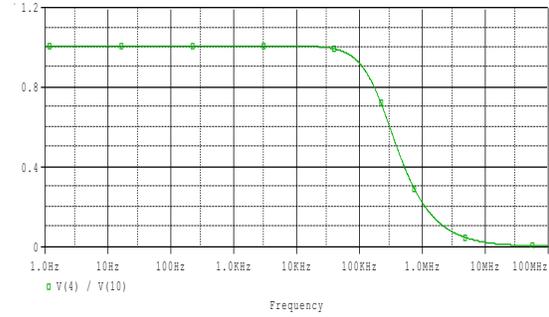


Figure 5:- : Response of voltage –mode lossless integrator for AC input (response of first order low-pass filter)

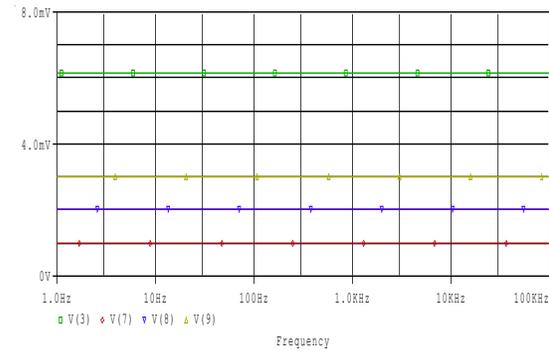


Figure 6:- Response of a voltage-mode adder circuit

IV. SINGLE INPUT MULTIPLE OUTPUT BIQUADRATIC FILTERS

4.1 KHN Biquadratic Filters:

It can be constructed by cascading two lossless integrators to obtain all the five desired filter transfer functions namely:

- i) Lowpass Response. (2.3)
- ii) Highpass Response. (2.3)
- iii) Band pass Response. (2.4)
- iv) Notch Response. (2.4)
- v) All pass Response. (2.4)

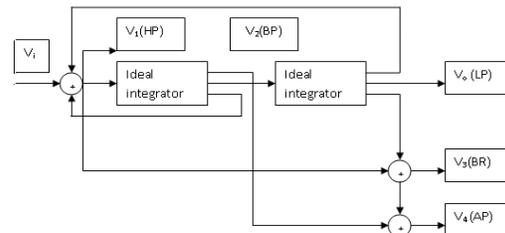


Figure 7:- Voltage-mode KHN-equivalent biquad

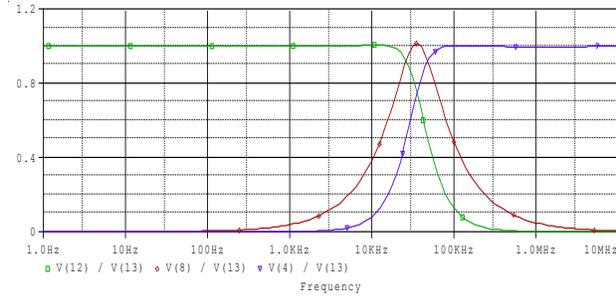


Figure 8:- Simulated response of voltage-mode KHN-equivalent biquad

4.2 MATHEMATICAL EXPRESSION

$$\frac{V_o}{V_2} = \frac{g_{m2}}{sC_2} \tag{3.1}$$

$$\frac{V_2}{V_1} = \frac{g_{m1}}{sC_1} \tag{3.2}$$

$$V_1 = V_i - V_o - V_2 \tag{3.3}$$

From eqns 3.1 & 3.2 we have,

$$V_1 = \frac{s^2 C_1 C_2}{g_{m1} g_{m2}} V_o$$

Putting values of V1 & V2 in Eqn 3.3

$$\frac{V_o}{V_i} = \frac{\frac{g_{m1} g_{m2}}{C_1 C_2}}{s^2 + s \left[\frac{g_{m1}}{C_1} \right] + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

Thus, we can say that the equation-(3.5) represents a lowpass response. Similarly, when the value of V_o is substituted from equation-(3.5) in equation-(3.1) and (3.4) respectively we obtain the expression for the currents V₁ and V₂ in terms of the input voltage V_i as follows:

$$\left(\frac{V_2}{V_i} \right)_{BPF} = \frac{s \frac{g_{m1}}{C_1}}{s^2 + s \left[\frac{g_{m1}}{C_1} \right] + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

$$\left(\frac{V_1}{V_i} \right)_{HPF} = \frac{s^2}{s^2 + s \left[\frac{g_{m1}}{C_1} \right] + \frac{g_{m1} g_{m2}}{C_1 C_2}}$$

Thus, we can say that the equation-(3.6) and (3.7) respectively represents a band pass response and a highpass response.

Similarly, the currents V₃ and V₄ can be written as:

$$V_3 = V_1 + V_o$$

And

$$V_4 = V_3 - V_2$$

Where voltages V₃ & V₄ represents band reject response and all pass response respectively.

The expressions for the filter cut-off frequency (ω_o) and the quality factor (Q) can be obtained from the above current transfer function and they are given by:

$$\omega_o = \frac{1}{\sqrt{C_1 C_2}}$$

$$Q = \sqrt{\frac{C_1}{C_2}}$$

V. CONCLUSIONS

A group of voltage-controlled circuits using the OTA as the basic active element have been presented. The characteristics of these circuits are adjusted with the externally accessible dc amplifier bias current. Most of these circuits utilize a very small number of components. Applications include amplifiers, controlled impedances, and filters. Higher-order continuous-time voltage-controlled filters such as the common Butterworth, Chebyshev, and Elliptic types can be obtained. In addition to the voltage control characteristics, the OTA based circuits show promise for high-frequency applications where conventional op amp based circuits become bandwidth limited. The major factor limiting the performance of OTA based filters using commercially available OTAs is the severely limited differential input voltage capability inherent with conventional differential amplifier input stages. Recent research results suggested significant improvements in the input characteristics of OTAs can be attained. All the realized circuits were tested using SPICE and the verified results confirms the theoretical value.

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