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Scientific Research

VDTA-Based Wave Active Filter

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Abstract

In this paper we present a wave active filter based on Voltage Differencing Transconductance Amplifiers (VDTAs). The synthesis of active filters basically based on processing of wave quantities. The wave method is presented for basic building blocks of active filters *i.e.* a series inductor and parallel capacitor through which realization of various active circuits is made by appropriate connections. The proposed wave active filter is verified by realizing a 4th order low pass Butterworth filter using SPICE simulation with 0.18 μm TSMC CMOS technology parameters.

Keywords

Voltage Differencing Transconductance Amplifier, Wave Active Filter, Voltage-Mode Filter

1. Introduction

The high order active filters can be realized by imitating the behavior of elements of LC ladder prototype filters and the approach for the designing of these filters has been already discussed in the literature [1]-[6] and the references cited therein. The purpose of the method was to derive active filters based on scattering parameters. Synthesis of active filters is based on the use of wave quantities, hence the scattering matrix will play an important role in the concept, as already discussed in the reference [1] and [2]. Wave active filters using various Active Building Blocks (ABB) are available in the literature [3]-[6] such as Current Feedback Operational Amplifiers [3], Differential Voltage Current Conveyor Transconductance Amplifier [4], Current Controlled Differential Difference Current Conveyor Transconductance Amplifier [5] and Operational Trans-Resistance Amplifier [6].

This paper presents the realization of wave active filter using a recently introduced ABB VDTA. The advantages and usefulness of VDTA are discussed in references [7]-[12].

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Wave equivalent is developed for an inductor in series branch and for a capacitor in parallel branch using VDTAs. The workability of 4th order low pass Butterworth filter is thus verified through SPICE simulation using 0.18 µm TSMC CMOS technology parameters.

2. VDTA Description

The VDTA is a recently introduced active element which has two voltage inputs and two kinds of current output. The symbol of VDTA is shown in **Figure 1** and its CMOS implementation is shown in **Figure 2** [7], where the input terminals are denoted as V_P and V_N and output terminals are Z, X^+ and X^-. The terminal relationship of VDTA can be described by the following set of equations:

$$\begin{bmatrix} I_Z \\ I_{X^+} \\ I_{X^-} \end{bmatrix} = \begin{bmatrix} g_{m_1} & -g_{m_1} & 0 \\ 0 & 0 & g_{m_2} \\ 0 & 0 & -g_{m_2} \end{bmatrix} \begin{bmatrix} V_{V_P} \\ V_{V_N} \\ V_Z \end{bmatrix} \quad (1)$$

The CMOS realization of VDTA is shown in **Figure 2** with,

$$g_{m_1} = (g_3 + g_4)/2 \quad (2a)$$

$$g_{m_2} = (g_5 + g_8)/2 \ \text{ or } \ g_{m_2} = (g_6 + g_7)/2 \quad (2b)$$

where g_i is the called as the Transconductance value of i^{th} transistor defined by

$$g_i = \sqrt{I_{Bi} \cdot \mu_i . C_{ox} \cdot \frac{W}{L}} \quad (3)$$

3. Basic Wave Equivalent Using VDTA

3.1. Basic Wave Equivalent

For defining the practicality of the filter the wave method is used and defined by the scattering matrix S. The incident and reflected voltage waves are illustrated as A_i and B_i respectively for two port network of **Figure 3** and are related by the following relation:

$$A_i = V_i + I_i R_i \, , \, B_i = V_i - I_i R_i \quad (4)$$

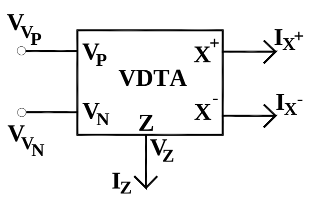


Figure 1. Symbol of VDTA.

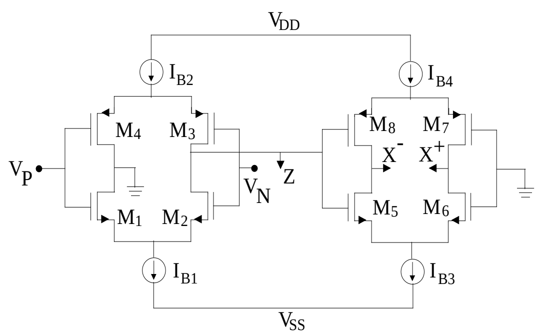


Figure 2. CMOS implementation of VDTA [7].

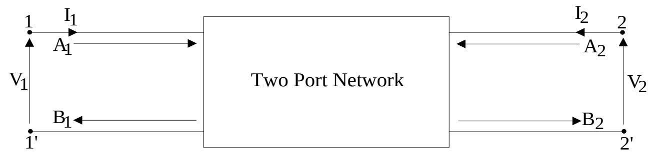


Figure 3. Incident waves A_1, A_2 and reflected waves B_1, B_2 for two port network.

Equation (4) can be expressed in terms of scattering matrix S as

$$\begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = S \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} \tag{5}$$

The series inductor L and parallel capacitor C can be described in terms of scattering parameter given by Equation (6) for L and C respectively.

$$S = \frac{1}{1+s\tau}\begin{bmatrix} s\tau & 1 \\ 1 & s\tau \end{bmatrix} \text{ and } S = \frac{1}{1+s\tau}\begin{bmatrix} -s\tau & 1 \\ 1 & -s\tau \end{bmatrix} \tag{6}$$

By going through the concept of wave filtering using the scattering parameter description, the incident waves (A_i) and the reflected waves (B_i) of an inductor (L) in series branch, are expressed as Equations (7) and (8).

$$B_1 = A_1 - \frac{1}{1+s\tau}(A_1 - A_2) \tag{7}$$

$$B_2 = A_2 + \frac{1}{1+s\tau}(A_1 - A_2) \tag{8}$$

where $\tau = L/2R$ is time constant and R is the characteristic resistance assigned at each port named port resistance [1] [2]. Similarly for a capacitor (C) in shunt branch the equations are (9) and (10) where $\tau = RC/2$.

$$-B_1 = A_1 - \frac{1}{1+s\tau}(A_1 - A_2) \tag{9}$$

$$B_2 = -A_2 + \frac{1}{1+s\tau}(A_1 + A_2) \tag{10}$$

Equations (7), (8), (9) and (10), can be realized by the use of following processes: 1) Lossy Integration-Subtraction, 2) Subtraction and 3) Summation.

3.2. Lossy Integration-Subtraction

A Lossy integration-subtraction configuration is shown in **Figure 4**. It uses a single VDTA, a parallel combination of resistor R_2 and capacitor C_d at output terminal X^+ and also a grounded resistor R_1 at output terminal Z.

The input-output relationship is given by the following equation:

$$V_O = \frac{1}{1+s\tau}(V_{in1} - V_{in2}) \tag{11}$$

where the realized time constant $\tau = R_2C_d$, $g_{m1}R_1 = 1$ and $g_{m2}R_2 = 1$. On comparing Equation (11) with equations (7) and (8), it is accomplished that the following condition must be fulfilled: $R_2C_d = L/2R$. Considering, port resistance $R = R_2$, the value of capacitor in wave active realization is given by:

$$C_d = L/2R^2 \tag{12}$$

Subtraction:

To implement the subtraction operation using VDTA, the configuration is depicted in **Figure 5**.

$$V_O = (V_{in1} - V_{in2}) \text{ with } g_{m1}R_1 = 1 \text{ and } g_{m2}R_2 = 1 \tag{13}$$

Summation:

A VDTA based summation configuration is shown in **Figure 6**. It consists of two VDTAs. The first VDTA

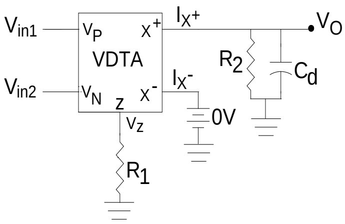


Figure 4. Lossy integration-subtraction using VDTA.

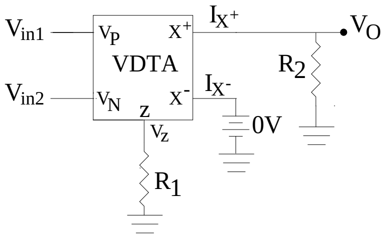


Figure 5. Subtraction using VDTA.

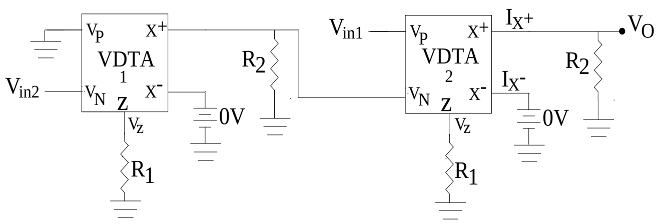


Figure 6. Summation using VDTA.

reverses the input V_{in2} which is then subtracted from input V_{in1} by second VDTA to give,

$$V_O = \left(V_{in1} + V_{in2}\right) \text{ with } g_{m1}R_1 = 1 \text{ and } g_{m2}R_2 = 1 \tag{14}$$

Using the blocks in **Figure 4**, **Figure 5** and **Figure 6**, the resultant wave equivalent of an inductor in series-branch as given by Equations (7) and (8) is shown in **Figure 7** and its symbolic representation is shown in **Figure 8**.

Similarly, the resultant wave equivalent of a capacitor in shunt-branch as given by Equations (9) and (10) is shown in **Figure 9** and its symbolic representation is shown in **Figure 10**.

4. Complete Set of Wave Equivalents

According to the wave method, the wave flow diagrams that could be employed for designing active filters are summarized in **Table 1**. The required inversion blocks could be obtained by employing the subtraction block in **Figure 5** with the condition that V_{in1} = 0.

To accomplish the construction of whole filter circuit, the main points are: port resistances are assumed to be equal and the cross-cascade connection of the incident and reflected waves is applied because the incident wave at each port equals the reflected wave at the foregoing port [1]-[6]. Wave equivalents are substituted in place of individual capacitors and inductors and the complete structure is then achieved by cascading the respective wave equivalents.

5. Simulation Results

Simulations are performed by using SPICE program with TSMC CMOS 0.18 µm process parameters. The aspect ratios of various transistors used are given in **Table 2**. Supply voltages are taken as V_{DD} = −V_{SS} = 0.9 V and

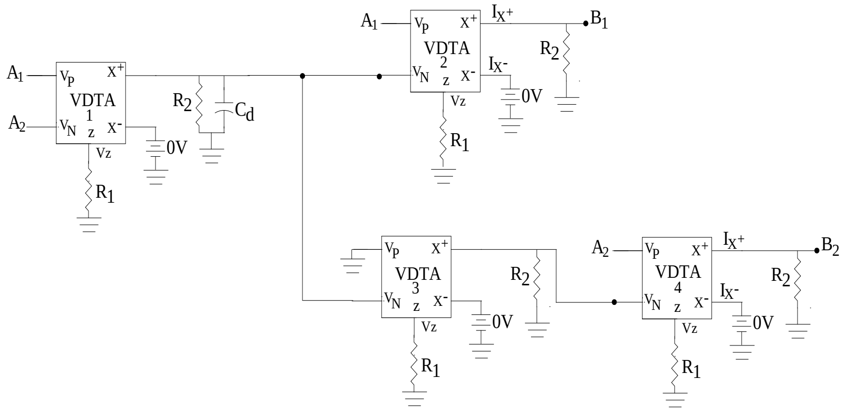


Figure 7. VDTA based wave equivalent of an inductor in series branch.

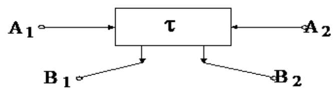


Figure 8. Symbolic representation wave equivalent of series inductor.

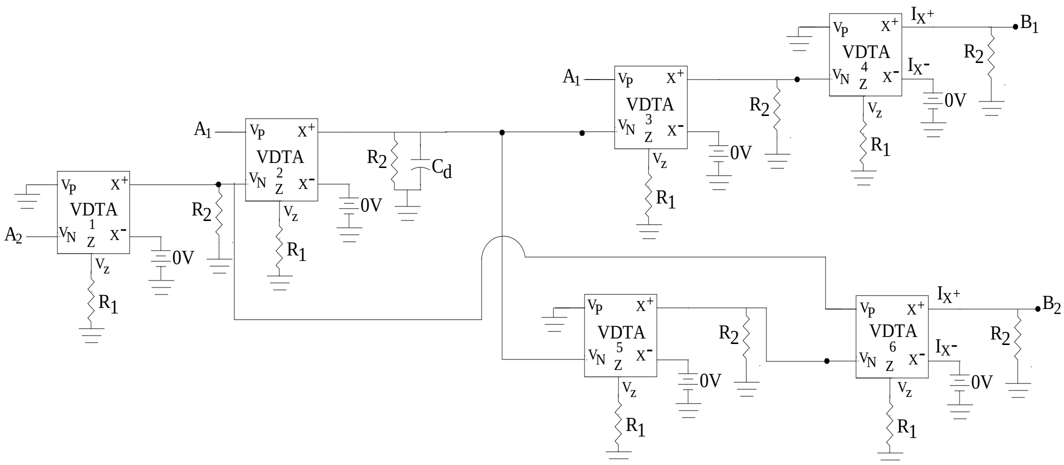


Figure 9. VDTA based wave equivalent of a capacitor in parallel branch.

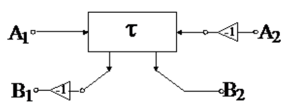


Figure 10. Symbolic representation of wave equivalent of parallel capacitor.

the transconductances of VDTA were controlled by bias currents $I_{B1} = I_{B2} = I_{B3} = I_{B4} = 513.36$ uA. Thus, the transconductance were found to be $g_{m1} = g_{m2} = 1$ mA/V. For verification of the suggested method defined in Sections 3 and 4, a 4th order low pass Butterworth filter (**Figure 11**) has been taken for experiment. The component values used are $R_S = R_L = 1$ KΩ, $L_1 = 0.2437$ mH, $L_2 = 0.5884$ mH, $C_1 = 0.5884$ nF, $C_2 = 0.2437$ nF.

The filter circuit is implemented using the wave equivalents of series inductor and parallel capacitor. The theoretically predicted value of cutoff frequency and also measured by the response of 4th order low pass Butterworth filter shown in **Figure 12** is 511.48 KHz. The resistors R_1, R_2 are chosen to be 1 kΩ according to $g_{m1}R_1 = g_{m2}R_2 = 1$. The values of capacitor C_d for wave equivalent of series inductors (L_1, L_2) are 0.12185 nF, 0.294 nF and for wave equivalent of shunt capacitors (C_1, C_2) are 0.2942 nF, 0.12185 nF. The complete structure obtained by cascading the wave equivalents is shown in **Figure 13** and has been simulated using VDTA based wave

Table 1. Wave equivalent of elementary two port consisting of single element.

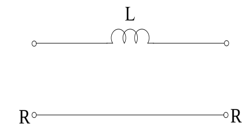
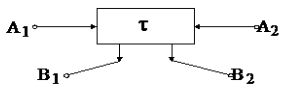
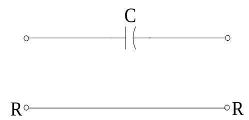
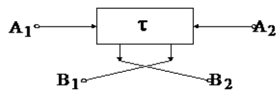
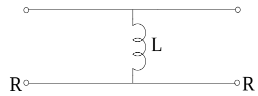
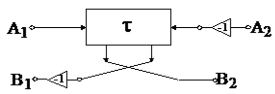
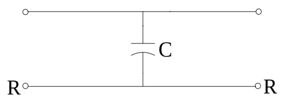
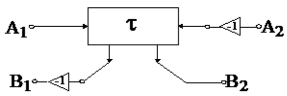
Elementary two port	Wave equivalent	Time constant	Capacitor value for VDTA based wave equivalent
		$\tau = \frac{L}{2R}$	$C_d = L/2R^2$
		$\tau = 2RC$	$C_d = 2C$
		$\tau = \frac{2L}{R}$	$C_d = 2L/R^2$
		$\tau = \frac{RC}{2}$	$C_d = C/2$

Table 2. Transistors aspect ratios for VDTA.

Transistors	W (μm)	L (μm)
M_1, M_2, M_5, M_6	3.6	0.36
M_3, M_4, M_7, M_8	16.64	0.36

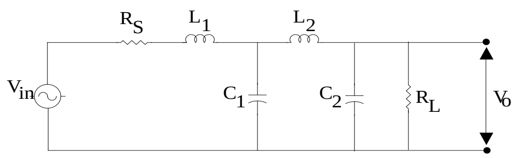


Figure 11. 4th order low pass butterworth filter.

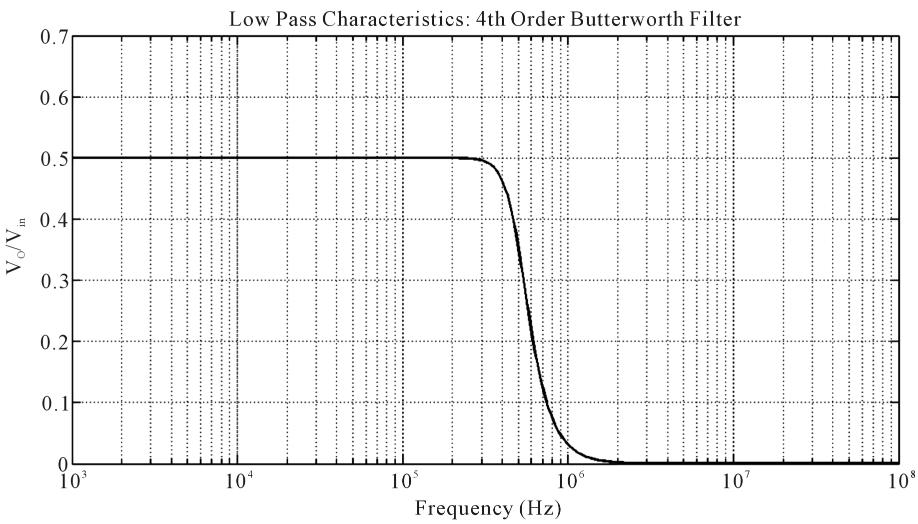


Figure 12. Frequency response of 4th order low pass butterworth filter.

equivalents. **Figure 14** and **Figure 15** display the simulated filter responses for 4th order low pass (V_O) and its complementary high pass (V_{OC}) respectively. The measured cutoff frequency of the filter was 503.52 KHz.

6. Conclusion

A new wave active filter is presented using recently introduced ABB VDTA. VDTAs are used to design lossy integration-subtraction, subtraction and summation blocks, which are the main steps in realizing the wave active filter. The wave method is verified by realizing the 4th order low pass and high pass responses. The proposed wave filter may be designed by using other ABBs which requires lesser power consumption than VDTAs. SPICE

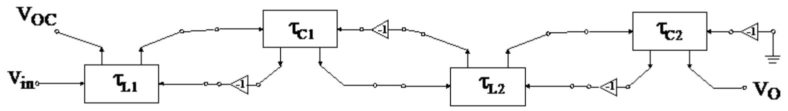


Figure 13. Wave equivalent of 4th order butterworth filter.

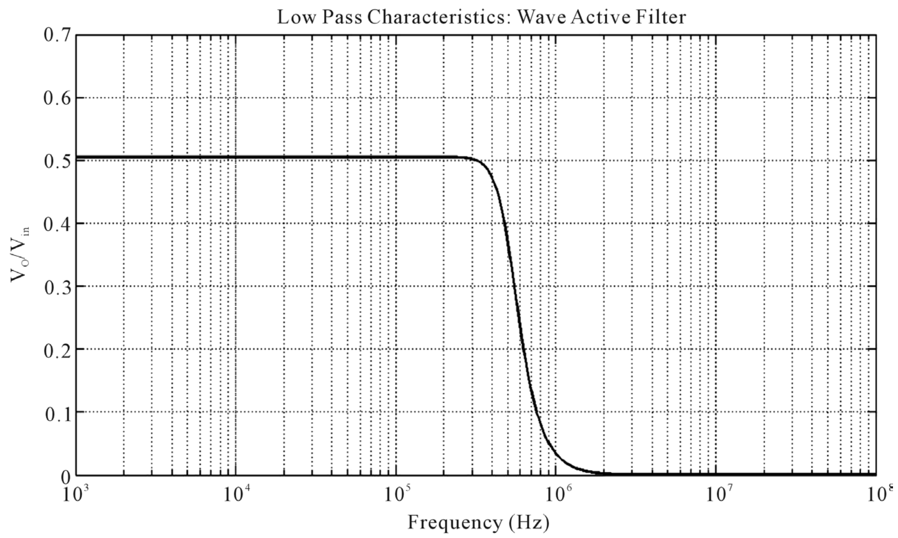


Figure 14. Frequency response of 4th order low pass filter: wave active filter.

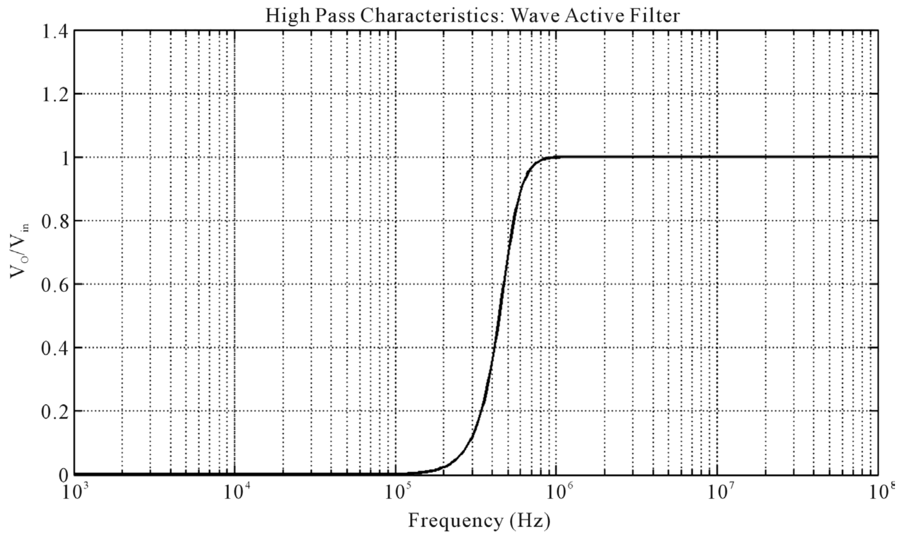


Figure 15. Frequency response of 4th order complementary high pass filter: wave active filter.

simulation results thus confirm the operation of wave active filter with 0.18 µm TSMC CMOS technology parameters.

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