Universal Filters Using Operational Transresistance Amplifiers

khaled N. Salama and Ahmed M. Soliman

Abstract **A new generalized universal filter using the Operational Transresistance Amplifier is proposed. Two different configurations leading to twelve different universal filters are presented. All reported filters have independent control on the bandwidth, quality factor and gain. Detailed analysis taking the effect of the finite transresistance gain into consideration is given. Self compensation that requires no additional elements of some of the proposed circuits is presented. Simulations are in good agreement with the theoretical analysis.**

Keywords **Operational Transresistance Amplifier, Universal Filters.**

1. Introduction

The growing demand for mobile communications has led to high level of chip integration and directed research towards the field of high frequency applications [1]. Recently new analog building blocks have been developed to overcome the finite gain-bandwidth product associated with traditional operational amplifiers (op amps) [2][3][4]. Although the Operational Transresistance Amplifier (OTRA) is commercially available from several manufacturers under the name current differencing amplifier or Norton amplifier [5][6], it hasn't gained attention until recently. Unfortunately, the OTRA did not make a real breakthrough in active RC filters because these commercial realizations don't provide a true virtual ground at the input terminals and they allow the input current to flow in one direction only. The former disadvantage limited the functionality of the OTRA, whereas the later forced designers to use external DC bias circuits leading to complex and unattractive designs [10]. Few recent realizations have been suggested to implement the OTRA [7][8]. The basic principle behind the design of the OTRA is to provide amplification of high frequency signals with the ease of using standard op amps. The OTRA can provide the previous advantage in addition to a constant bandwidth virtually independent of the gain. The Operational Transresistance Amplifier is a three terminal analog building block with a describing matrix in the form:

$$\begin{bmatrix} V_+ \\ V_- \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_+ \\ I_- \\ I_o \end{bmatrix} \qquad (1)$$

Both the input and output terminals are characterized by low impedance. The input terminals are virtually grounded leading to circuits that are insensitive to the stray capacitance as reported in[9]. For ideal operation, the transresistance gain, R$_m$, approaches infinity forcing the input currents to be equal. Thus the OTRA must be used in a negative feedback configuration in a way that is similar to op amps.

2. Continuous time Active Filters

Continuous time filters using conventional op amps, transconductors and switched capacitors are now widely accepted in industry where they are used in applications involving direct signal processing especially for medium dynamic range applications [4]. Usually two inverting integrators are cascaded and a third inverter allows closing the overall loop with the proper phase. This idea is behind many of the biquad filter structures available. The active elements count in these structures can be reduced, if a true non inverting integrator could be build with a single element. This allows using a dual amplifier instead of three op amps or a quad [10]. Unfortunately this can't be done with conventional op amps but easily done using the OTRA. In addition op amp filters suffer from limited slew rate and are gain bandwidth limited.

Although gm-C filters can provide high frequency response, weighted sum integrators and weighted sum adders has to be performed with a number of gm-C cells with different gm factors. This is easily achieved using a single OTRA due to the presence of two virtually grounded terminals reducing the number of active elements leading to less power consumption and less noise to the whole system.

Switched-C filters are very accurate in the range of few kilohertz but become very power consuming in the range of Megahertz. Thus the applications that the OTRA will be useful in are video applications which are in the range of few Megahertz. Universal filters are widely accepted. They are capable of providing High pass, Band pass, Low pass, Band stop and All pass responses using the appropriate admittance with the same active element configuration [11][12]. Fig.1 shows the proposed configuration for a universal filter employing minimum number of active elements.

Assuming ideal active components, the generalized transfer function is given by

$$T(s) = \frac{Y_3Y_7 + Y_1Y_6 - Y_2Y_6 - Y_5Y_7}{Y_7Y_8 + Y_4Y_6} \qquad (2)$$

Different approaches can be considered in choosing the admittances [12]. One possible choice is to set either

$$Y_2 = 0 \qquad (3)$$

Or

$$Y_5 = 0 \qquad (4)$$

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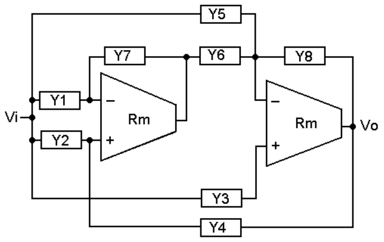

Fig. 1. Proposed Universal Filter Circuit using Operational Transresistance Amplifiers.

3. The Effect of Non ideal OTRA

In this section, the effect of the major nonidealities inherent in the OTRA on the proposed filters are considered and self compensation is introduced. Considering a single pole model for the transresistance gain, R$_m$, then

$$R_m(s) = \frac{R_o}{1 + \frac{s}{w_o}} \tag{5}$$

For filter applications which are intended for high frequencies, the transresistance gain, R$_m$(s), reduces to:

$$R_m(s) \approx \frac{1}{C_p s} \tag{6}$$

Where

$$C_p = \frac{1}{R_o w_o} \tag{7}$$

and eq.(2) reduces to:

$$T(s) = \frac{Y_3(Y_7 + C_p s) + Y_1 Y_6 - Y_2 Y_6 - (Y_7 + C_p s)Y_5}{(Y_7 + C_p s)(Y_8 + C_p s) + Y_4 Y_6} \tag{8}$$

For complete compensation, the admittances Y$_7$ and Y$_8$ must contain capacitor branches. In that case the filters can be designed taking the magnitude of C$_p$ into consideration, by subtracting its magnitude from C$_7$ and C$_8$. Thus the effect of C$_p$ can be absorbed in the integrating capacitances C$_7$ and C$_8$ without using any additional elements and achieving complete self compensation. Whereas considering the single pole model for op amps, either complex passive compensation techniques using external capacitors or active compensation using additional op amps is possible.

Two different configurations can be derived from eq. (2) as indicated by eq. (3) and eq. (4). Table 1 represents the first configuration. Six different choices of admittances which are limited to a maximum of nine admittances with the minimum possible number of capacitors are presented. Considering the second design in Table 1, the generalized transfer function is given by:

$$T(s) = \frac{C_3 C_7 s^2 + C_7(G_3 - G_5)s + G_1 G_6}{C_7 C_8 s^2 + C_7 G_8 s + G_4 G_6} \tag{9}$$

Table 2 represents the second configuration. Six different choices of admittances which are limited to a maximum of five capacitors are presented. Considering the fifth design in Table 2, the generalized transfer function is given by:

$$T(s) = \frac{C_3 C_7 s^2 + (C_1 - C_2)G_6 s + G_1 G_6}{C_7 C_8 s^2 + C_7 G_8 s + G_4 G_6} \tag{10}$$

It is clear from eq.(9) and eq.(10) that High pass, inverting Band pass, non inverting Band pass, Low pass, Band stop and All pass responses can be realized using appropriate choice of admittances. Some of the proposed filters are self compensated, While others which do not have capacitor branches in their feedback network need additional capacitors to compensate for the finite transresistance gain R$_m$. These additional capacitors of magnitude, C$_p$, are connected between the output and noninverting input of the OTRA.

4. HSpice Simulation Results

Simulations were conducted using the OTRA presented in [9]. The OTRA used has the following parameters:
$C_p = 5.5pF, R_o = 2.2M\Omega$

Fig.2 represents the ideal, compensated and uncompensated results for a low pass filter designed to give a Butterworth response where:
$C_7 = C_8 = 20pF, C_7' = C_8' = 14.5pF$
$R_1 = R_4 = R_6 = 5k\Omega, R_8 = 3.535k\Omega$

From simulations the percentage error in the frequency, $100(f - f_o)/f_o$, is -0.5%, -15% for the compensated and uncompensated cases respectively.

Fig.3 represents the ideal, compensated and uncompensated band pass responses having $Q = 40$ where:
$C_7 = C_8 = 20pF, C_7' = C_8' = 14.5pF$
$R_4 = R_6 = 10k\Omega, R_5 = 40k\Omega, R_8 = 400k\Omega$

From simulations the percentage error in the frequency, $100(f - f_o)/f_o$, is -0.5%, -17% for the compensated and uncompensated cases respectively. The percentage error in Q, $100(Q - Q_o)/Q_o$, is 12%, 5% for the compensated and uncompensated cases respectively.

5. Conclusions

A generalized universal filter using the OTRA is given. Twelve filter circuits having independent control on the bandwidth, quality factor and gain are derived from the

Table 1. Admittances choice for $Y_2 = 0$

Y_1	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Self Cmp.
G_1	C_3s	G_4	G_5	G_6	$G_7 + C_7s$	C_8s	YES
G_1	$G_3 + C_3s$	G_4	G_5	G_6	C_7s	$G_8 + C_8s$	YES
G_1	C_3s	G_4	G_5	$G_6 + C_6s$	C_7s	C_8s	YES
C_1s	G_3	C_4s	C_5s	$G_6 + C_6s$	G_7	G_8	NO
$G_1 + C_1s$	C_3s	G_4	G_5	G_6	C_7s	$G_8 + C_8s$	YES
G_1	$G_3 + C_3s$	$G_4 + C_4s$	G_5	G_6	C_7s	C_8s	YES

Table 2. Admittances choice for $Y_5 = 0$

Y_1	Y_2	Y_3	Y_4	Y_6	Y_7	Y_8	Self Cmp.
C_1s	G_2	G_3	C_4s	$G_6 + C_6s$	G_7	G_8	NO
$G_1 + C_1s$	G_2	G_3	$G_4 + C_4s$	C_6s	G_7	G_8	NO
G_1	C_2s	C_3s	G_4	G_6s	$G_7 + C_7s$	C_8s	YES
G_1	C_2s	$G_3 + C_3s$	G_4	G_6	C_7s	$G_8 + C_8s$	YES
$G_1 + C_1s$	C_2s	C_3s	G_4	G_6s	C_7s	$G_8 + C_8s$	YES
G_1	C_2s	$G_3 + C_3s$	$G_4 + C_4s$	G_6	C_7s	C_8s	YES

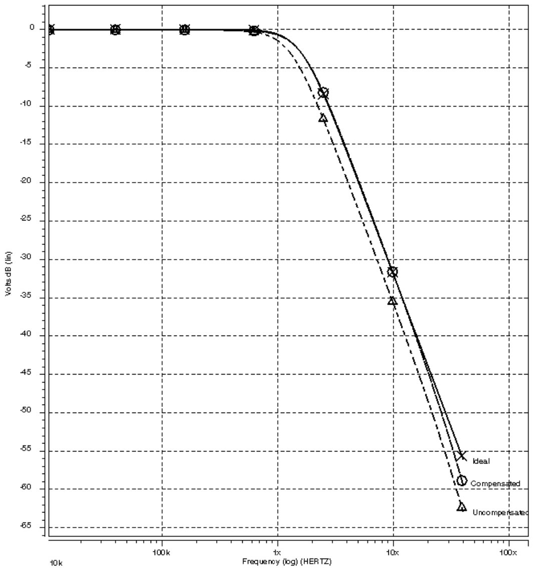

Fig. 2. Ideal, Uncompensated and Compensated frequency responses for a Lowpass Butterworth filter.

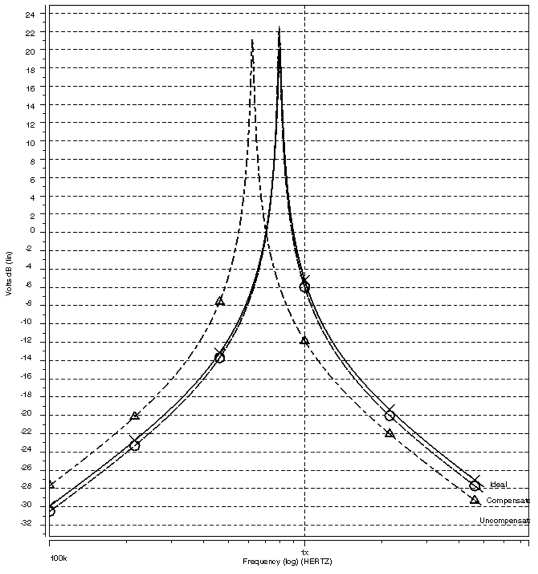

Fig. 3. Ideal, Uncompensated and Compensated frequency responses for a Band pass filter with Q=40.

basic configuration. It is found that the effect of the stray capacitance can be absorbed in some of the proposed filters. HSpice simulations that confirm theoretical analysis are included.

References

[1] Razavi, B.: 1998, RF Microelectronics. Prentice Hall,1998.

[2] Wong, J.: Current-Feedback op amps extend high-frequency Performance. Electronic Design News (1989), 211-215.

[3] Elwan, H.; Soliman, A.: CMOS Differential Current Conveyors and Applications for Analog VLSI. Analog Integrated Circuits and Signal Processing, 11, (5), 1996, 35-45.

[4] Toumazou, C.; Lingey, F.; Haigh, D.: Analogue IC design: the current-mode approach. Peter Peregrinus, 1990.

[5] Brodie, J.: A notch filter employing current differencing operational amplifier. International Journal of Electronics, 41, 5 ,(1976), 501-508.

[6] National Semiconductor Corp.: The LM3900: a new current differencing 1quad of the input amplifiers. Linear Applications Data Book, 1986.

[7] Chen, J.; Tsao,H.; Chen,C.: Operational Transresistance Amplifier Using CMOS Technology. Electronics Letters, 28, (22), (1992), 2087-2088.

[8] Chui, W.; Tsay, J.; Liu, S.; Tsao, H.; Chen,J.: Single-capacitor MOSFET-C integrator using OTRA. Electronics Letters, 31, (21), (1995), 1796-1797.

[9] Chen, J.; Tsao, H.; Liu, S.; Chui, W.: Parasitic-capacitance-insensitive current-mode filters using operational transresistance amplifiers. IEE Proceedings Circuits Devices and Systems, 142, (3), (1995), 186-192.

[10] National Semiconductor Corp.: Designing with a new super fast dual Norton amplifier. Linear Applications Data Book, 1981.

[11] Sedra, A.; Smith, K.: Microelectronic Circuits. Holt, Rinehart and Wiunston Inc., 1991.

[12] Budak, A.: Passive and Active Network Analysis and Synthesis. Houghton Mifflin, 1974.