J. Pure Appl. & Ind. Phys. Vol.1 (3), 206-211 (2011)

An improved Active Low Pass Filter

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ABSTRACT

A new active low pass filter comprising of two general purpose operational amplifiers (OAs), four resistors and one capacitor is presented. The analytical expressions are obtained and the performance of the proposed circuit is examined in relation to the conventional circuit. Simulation and experimental results are presented which establish the superiority of the proposed low pass filter on the conventional circuit.

Keywords: operational amplifier, Active filter, Active low pass filter.

INTRODUCTION

A low pass active filter using operational amplifiers (OA), as shown in Figure1, finds numerous applications in various areas such as instrumentation.
A straight forward analysis of the active low pass filter, shown in Figure 1, using 1-pole OA model

$$A(s) = \frac{A_o\omega_o}{s+\omega_o} = \frac{\omega_t}{s+\omega} \quad (1)$$

gives

$$H(s) = \frac{V_0}{V_s} = G\frac{1}{s^2R_1C_1G\tau + s(R_1C_1 + s\tau) + 1} \quad (2)$$

with

$$\omega_t = \frac{1}{\tau}, G = 1 + \frac{R_f}{R} \text{ and } s \gg \omega_0 ,$$

where ω_0 is the first-pole frequency, ω_t is the unity gain bandwidth and $s = j\omega$. Note that $\omega_t = A_o\omega_o$
where A_0 is the dc open-loop gain of the op-amp.

Different methods have been used to improve the frequency response of active filters[1-5]. The present work aims at improving the frequency response of the circuit by minimizing its magnitude and phase errors. Such efforts have already been made with success and have been reported in the literature[6-9].

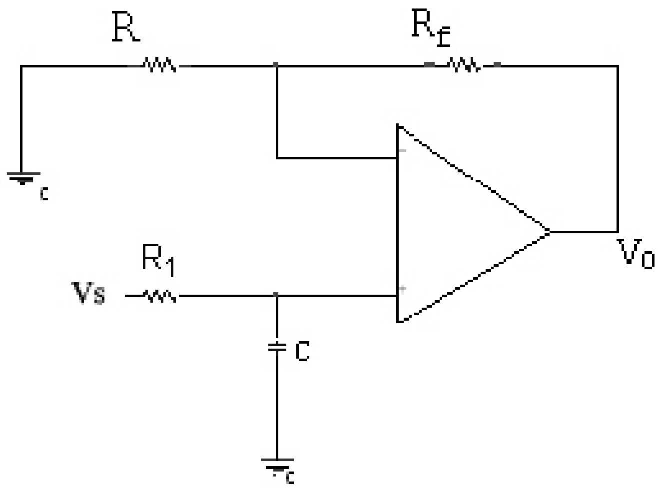

Figure 1. Conventional low pass filter

From Equation (2) it is possible to express the magnitude and phase errors of H(s) as the sum of two components,

$$|H(s)| = H_0[1+\varepsilon_H(s)] \tag{3}$$

$$\angle H(s) = \angle H_0 + \varepsilon_\phi(s) \tag{4}$$

Where $\varepsilon_H(s)$ and $\varepsilon_\phi(s)$ are the magnitude and phase errors respectively, and $H_0 and \angle H_0$ are the ideal magnitude and phase angles of Equation (2) at s=0. Note that for the low pass filter of Figure 1, $\angle H_0$ =0.

Using Equation (2), the new magnitude and phase errors in Equation (3) and (4) may be put in the form

$$\varepsilon_H(s) = -\frac{1}{2}\omega^2 G(G\tau^2 + R_1^{\,2}C_1^2) \tag{5}$$

$$\varepsilon_\phi(s) = -\omega(R_1C_1 + G\tau) \tag{6}$$

From Equations (5) and (6), it follows that the magnitude error is a second order term whereas the phase error is a first order term. In the paper, a new active low pass filter comprising two opamps, three resistors and one capacitor is described. Analytical expressions are obtained and necessary conditions are derived to realize the maximally flat magnitude and phase responses. The feature of this new low pass filter are compared with the conventional low pass filter, using one opamp, three resistors and one capacitor.

PROPOSED LOW PASS FILTER

The proposed low pass filter is shown in Figure 2.

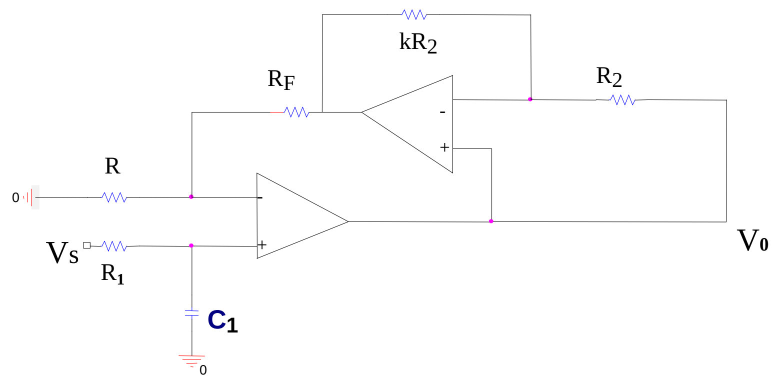

Figure 2: Proposed Low Pass filter

Assuming that the opamps are identical, a straight forward analysis of the circuit shown in figure 2, using 1-pole opamp model, gives the transfer function H(s) in the form

$$H(s)=\frac{V_0}{V_s}=\frac{G[1+(1+k)s\tau]}{1+S(R_1C_1+G\tau)+s^2[G\tau^2(1+k)+R_1C_1G\tau]+s^3R_1C_1G\tau^2(1+k)} \qquad (7)$$

Where $s \gg \omega_0$, $G=1+\frac{R_F}{R}$ and τ is the reciprocal of unity gain bandwidth of the opamp. Note that the transfer function in Equation (7) exhibits poles and zeroes in the left-half s-plane and further, that the denominator in Equation (7) satisfies the Routh-Hurwitz stability criterion [10].

Using Equation (7), the maximally flat magnitude response is obtained when

$$k=k_m=(\sqrt{2}-1)G-1 \qquad (8)$$

and maximally flat phase response is achieved for

$$k=k_\phi=G-1 \qquad (9)$$

Using Equation (7) $\varepsilon_H(s) and \varepsilon_\phi(s)$ defined by Equations (3) and (4) respectively, under conditions given by Equations (8) and (9) respectively, may be approximately put in the form

$$\varepsilon_H(s)=-\left[R_1C_1G\tau\left(R_1C_1+G\tau\right)+G^2\tau^3\left(1+k\right)\right]\frac{\omega^4}{12} \qquad (10)$$

$$\varepsilon_\phi(s)= -6R_1C_1G^2\tau^2\omega^3 \qquad (11)$$

It is seen from equations (10) and (11) that the magnitude error is a fourth order term whereas the phase error is a third order term, a distinct advantage over the conventional circuit where the magnitude error is a second order term and the phase error is a first order term

SIMULATION AND EXPERIMENTAL RESULTS

A computer simulation of the circuit shown in Figure 2 for its magnitude response is plotted in Figure 3 with G=3, $k=k_m=0.242$ and upper cut-off frequency 100kHz using 1-pole op-amp model with the parameters listed in Table1. The simulated magnitude response of the conventional low pass filter shown in Figure1 as well as experimental data for circuit shown in Figure 2 are also plotted in Figure 3 to facilitate comparison.

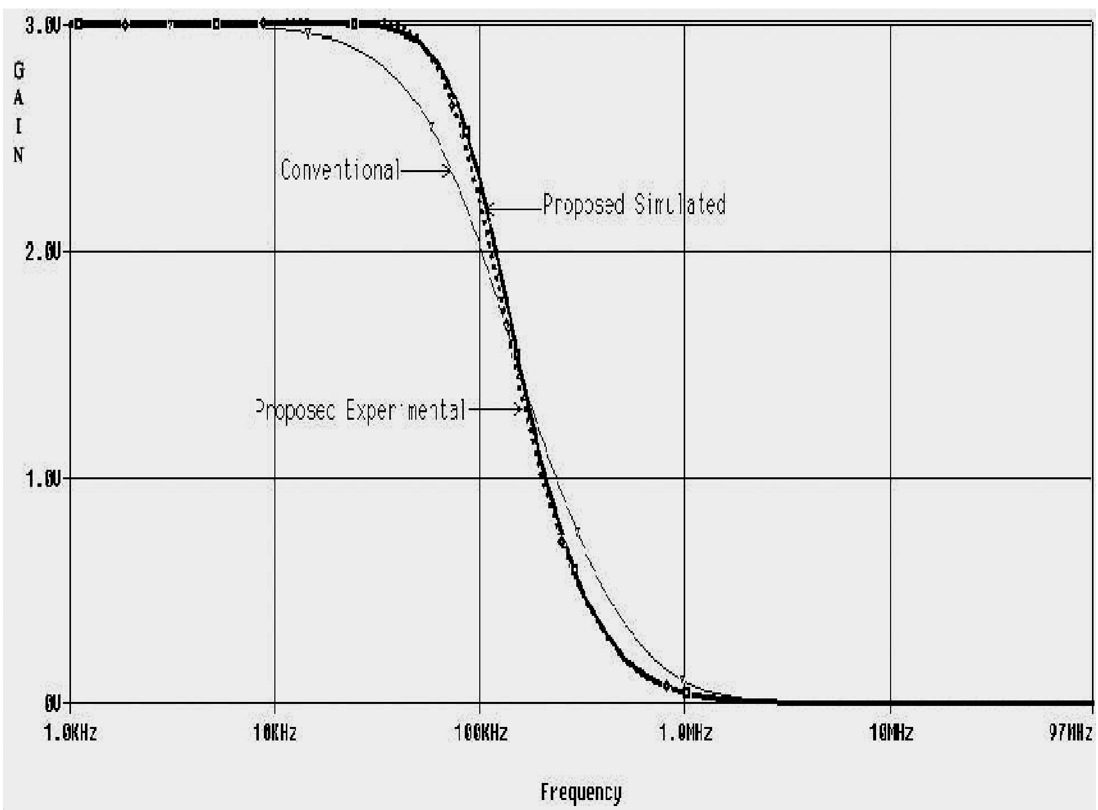

Figure 3: Simulated and experimental magnitude response of circuit in Figure 1 & 2 for dc gain =3 with k=0.242

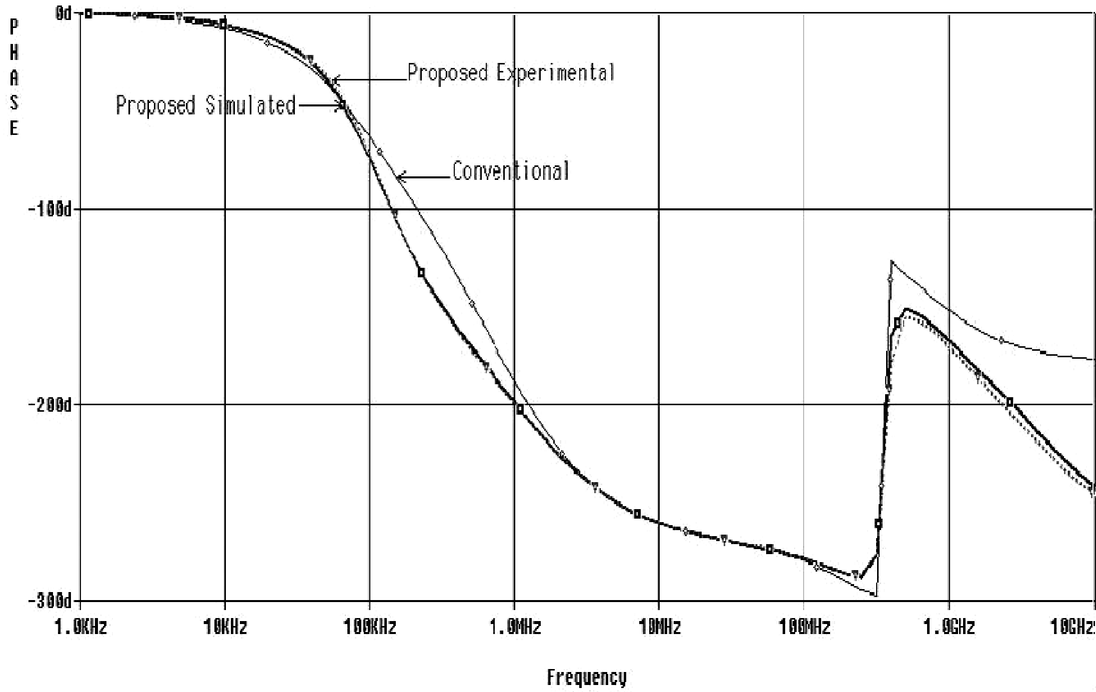

Figure 4: Simulated and Experimental Phase response of circuits of Figure 1 & 2 for gain=3 & k=2

It is seen from Figure 3 that the magnitude response of the proposed circuit is much better than the conventional low pass filter circuit. Moreover, the proposed circuit offers an extended frequency range over which the magnitude remains constant, which is a distinct advantage over the conventional circuit. The experimental data plotted in Figure 3 are seen to be in close agreement with the simulated curve for circuit shown in Figure 2. The minor deviation of the experimental data from the simulated curve may be attributed to the mismatching of the op-amps parameters and their deviation from the parameters used in simulation.

A complete simulation of the circuit shown in Figure 2 using 1-pole op-amp model for its phase response is plotted in Figure 4 with G = 3 and $k = k_\varphi=2$. The simulated phase response of the conventional circuit shown in Figure 1 as well as the experimental data for circuit shown in Figure 2 are also plotted in Figure 4 to facilitate comparison. It is seen from Figure 4 that the phase response of the proposed circuit is much better than the conventional circuit. The experimental data plotted in Figure 4 are seen to be in close agreement with the simulated curve for circuit shown in Figure 2. The minor deviation of the experimental data with the simulated curve may be attributed to the mismatching of op-amp's parameters and their deviation from the parameters used in simulation.

Table I: Model Parameters of op-amp

$$A_0 = 1.2\times 10^5$$
$$\omega_0 = \pi \times 9.2 rad/\sec$$
$$\omega_t = 3.47\times 10^6 rad/\sec$$

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