

Universal Filter Using Single Commercially Available IC: LT1228

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Abstract. In electrical and electronic engineering, the filter is very importance circuit. A voltage-mode three inputs single output second-order multifunction filter is presented in this paper. The proposed filter is based on RLC parallel circuit. The main active element is the commercially available IC from Linear Technology Inc, LT1228. The filter consists of single LT1228, single resistor and two capacitors. Five output second-order filter responses, namely band-pass (BP), band-stop (BS), high-pass (HP), low-pass (LP) and all-pass (AP) functions are achieved. Each output response can be selected without component matching condition and the requirement of double gain amplifier. The quality factor and natural frequency can be electronically controlled. PSpice simulation results suing macro model of LT1228 are in close agreement with the theory.

1 Introduction

In electrical and electronic engineering, the biquadratic or second order filter has been important building blocks [1]. Also, this filter is the basic block to design high order filter. Especially, the second order multifunction filter which provides many filter responses in the same circuit has been gained significant attention and has become an interesting research topic. The multiple-inputs single-output (MISO) universal filter is the interesting one and has been continuously proposed. In case of voltage mode MISO, the selection of output voltage by switching on or off the input voltages should be done without the matching condition of passive and active elements. Moreover, the additional double gain amplifier should not be required.

In literature, there are a lot of MISO universal filters [2]-[15]. Unfortunately, these MISO universal filters have some drawbacks for example, need of matching condition, requirement of additional double gain amplifier, electronic uncontrollability, requirement of many active and passive element. The active elements used in some previous MISO universal filter are not commercially available.

The contribution of this paper is to propose a second order voltage-mode MISO multifunction filter using commercially available IC, LT1228 [16] as the active element. The LP, HP, BP, BS and AP responses are achieved without changing circuit topology. The matching condition of the passive and active element is not required. Also the additional double gain voltage amplifier doesn't need. The quality factor and natural frequency can be electronically tuned. It consists of single LT1228, single resistor and two capacitors. Through PSpice simulation using commercially available

IC also demonstrates improvements in terms of performance.

2 Circuit configuration and analysis of the proposed filter

2.1 LT1228

Operational transconductance amplifier (OTA) has attracted considerable attention to design high performance electronics circuits. OTA is basically current mode devices and is used in high frequency applications. Mostly, its transconductance gain (g_m) can be electronically controlled which allows the OTA based circuits are controlled by microcontroller or microcomputer. Many commercial OTA ICs are available for example CA3080 from Intersil, LM13700 from National Semiconductor, MAX543 from MAXIM. The LT1228 from Linear Technology Inc is the interesting one. It is the combination of OTA and current feedback amplifier. The port name, electrical symbol and equivalent of LT1228 are illustrated in Fig. 1. The electrical characteristic is shown in Eq. (1).

$$\begin{pmatrix} I_{v+} \\ I_{v-} \\ I_y \\ V_x \\ V_w \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & R_T \end{pmatrix} \begin{pmatrix} V_+ \\ V_- \\ V_y \\ I_x \end{pmatrix} \quad (1)$$

where R_T is the transresistance gain. In an ideal case, R_T is typically very large and can be considered as infinite value. The g_m of LT1228 is controlled by DC bias current I_B as follows

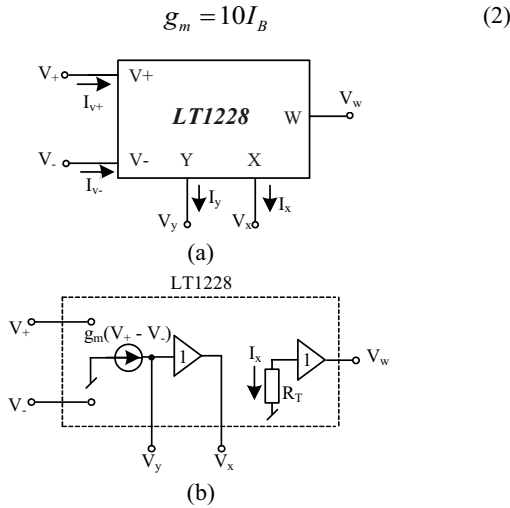


Figure 1. (a) Electrical symbol of LT1228 (b) its equivalent circuit.

2.2 Proposed three input single output voltage mode universal filter

The proposed filter is developed from passive RLC parallel circuit which consists of three input voltages, V_{in1} , V_{in2} and V_{in3} and single output voltage V_o . The filter constructed from single LT1228, single resistor and two capacitors as shown in Fig. 2. Based on RLC parallel circuit, the output voltage of the filter is obtained as

$$V_o = \frac{s^2 V_{in2} + s \frac{V_{in3}}{C_2 R} + \frac{g_m V_{in1}}{C_1 C_2 R}}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (3)$$

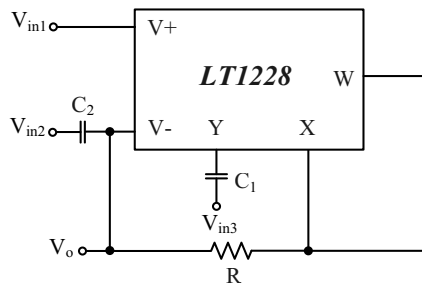


Figure 2. Three inputs single output voltage mode filter using single commercially available IC, LT1228.

From Eq. (3), a specific output filter responses can be selected by applying input voltage to node V_{in1} , V_{in2} and V_{in3} with following:

To obtain the band-pass (BP) function, the input voltage is applied at node V_{in3} while node V_{in1} and V_{in2} are grounded, then the voltage transfer function is obtained as

$$\frac{V_o}{V_{in}} = \frac{1}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (4)$$

To obtain the band-stop (BS) function, the input voltage is applied at node V_{in1} and V_{in2} , while node V_{in3} is connected to ground, then the voltage transfer function is obtained as

$$\frac{V_o}{V_{in}} = \frac{s^2 + \frac{g_m}{C_1 C_2 R}}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (5)$$

To obtain the high-pass (HP) function, the input voltage is applied at node V_{in2} , while node V_{in1} and V_{in3} are connected to ground, then the voltage transfer function is obtained as

$$\frac{V_o}{V_{in}} = \frac{s^2}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (6)$$

To obtain the low-pass (LP) function, the input voltage is applied at node V_{in1} , while node V_{in2} and V_{in3} are connected to ground, then the voltage transfer function is obtained as

$$\frac{V_o}{V_{in}} = \frac{\frac{g_m}{C_1 C_2 R}}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (7)$$

To obtain the all-pass (AP) function, the input voltage is applied at node V_{in1} , V_{in2} and V_{in3} , however, the inverting amplifier with unit gain is required at not V_{in3} , then the voltage transfer function is obtained as

$$\frac{V_o}{V_{in}} = \frac{s^2 - \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}}{s^2 + \frac{s}{C_2 R} + \frac{g_m}{C_1 C_2 R}} \quad (8)$$

From Eqs. (4) to (8), the natural frequency (ω_0) and quality factor (Q) can be obtained as

$$\omega_0 = \sqrt{\frac{g_m}{C_1 C_2 R}} \quad \text{and} \quad Q = \sqrt{\frac{g_m C_2 R}{C_1}} \quad (9)$$

If $g_m = 10I_B$ as written in Eq. (2) the natural frequency and quality factor of the proposed circuit are

$$\omega_0 = \sqrt{\frac{10I_B}{C_1 C_2 R}} \quad \text{and} \quad Q = \sqrt{\frac{10I_B C_2 R}{C_1}} \quad (10)$$

It is found from Eq. (10) that the Q and ω_0 can be electronically adjusted. In case $C_1=C_2$, it is found that the natural frequency can be adjusted without affecting the quality factor as follows

$$\omega_0 = \frac{1}{C} \sqrt{\frac{10I_B}{R}} \quad \text{and} \quad Q = \sqrt{10I_B R} \quad (11)$$

3 Simulation results

The PSpice simulation based on macro-model LT1228 IC was used to prove the performance of the filter. The proposed three-inputs single-output voltage-mode filter shown in Fig. 2 was bias with ± 5 voltage supplies. It was designed with following active and passive element values: $C_1 = C_2 = 1\text{nF}$, $R=1\text{k}\Omega$ and $I_B = 100\mu\text{A}$. With this value of components, the expected value of natural frequency in Eq. (10) is 159.154k Hz, while the simulation value of natural frequency was 157.398 kHz. The deviation was about 1.103%. The error between expected and simulation value of natural frequency suffered from the parasitic elements and tracking error from input to output of LT1228. The gain and phase responses, band-pass (BP), band-stop (BS), high-pass (HP), low-pass (LP) and all-pass (AP) functions are respectively shown in Figs. 3 to 7. The selection of output responses was done as stated in section 2. This confirms that the proposed filter can provide five standard second order filter responses without changing the circuit topology. The test of transient response of the proposed band-pass response filter was done by applying the input as sinusoidal voltage signal with 80mVp and $f = 160$ kHz into node V_{in3} , while nodes V_{in1} and V_{in2} were grounded. The measurement of input and output voltage is shown in figure 8. The tuning of natural frequency with electronic method was tested by adjusting bias current I_B as 100 μA , 200 μA and 400 μA . With these bias current, the simulated natural frequencies were located at 157.398 kHz, 222.844 kHz and 314.775 kHz, respectively as shown in Fig. 9. It is found that not only the natural frequency is changed, but the quality factor is also changed according to the expecting in Eq. (10). However, the tuning of natural frequency can be done without affecting the quality factor by simultaneously adjusting value of C_1 and C_2 as described in Eq. (11). This confirms by the results in Fig. 10. By varying $C_1=C_2$ with different values of 0.1nF, 1nF and 10nF, the simulated natural frequencies were 769.13 kHz, 78.705 kHz and 7.88 kHz. In this case the other component values were set as $I_B=500\mu\text{A}$ and $R=20\text{k}\Omega$. It is found from Fig. 10 that the natural frequency can be tuned with constant value of quality factor.

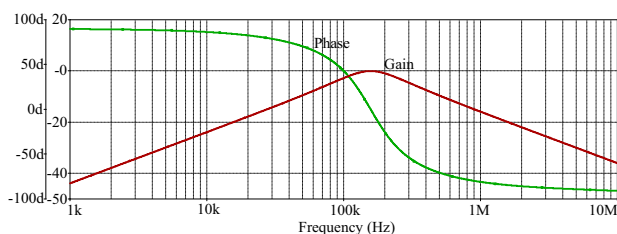


Figure 3. Simulated gain and phase responses for BP filter.

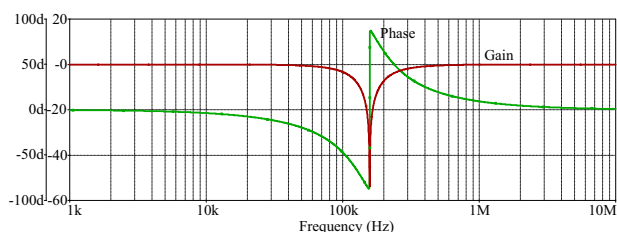


Figure 4. Simulated gain and phase responses for BS filter.

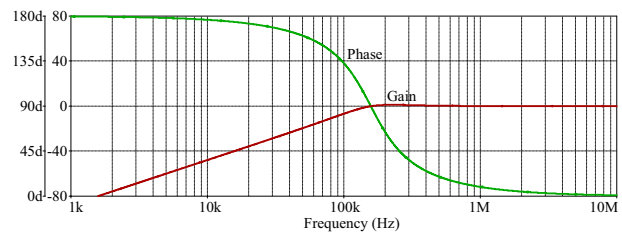


Figure 5. Simulated gain and phase responses for HP filter.

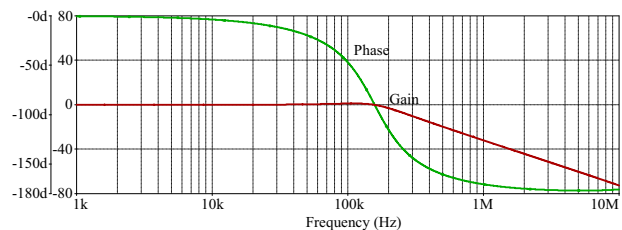


Figure 6. Simulated gain and phase responses for LP filter.

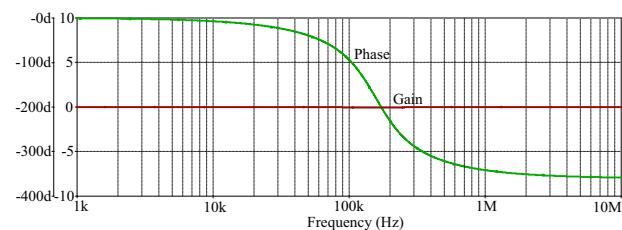


Figure 7. Simulated gain and phase responses for AP filter.

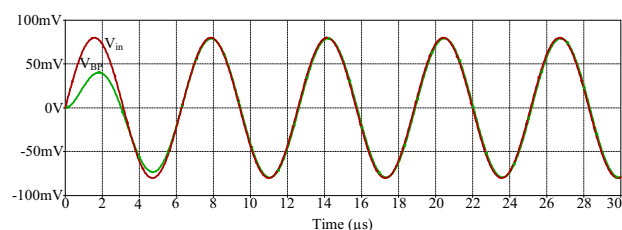


Figure 8. Transient response for BP function.

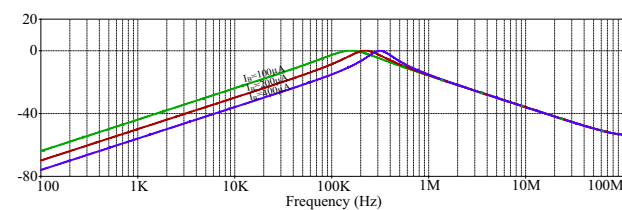


Figure 9. Simulated BP response for three different I_B values

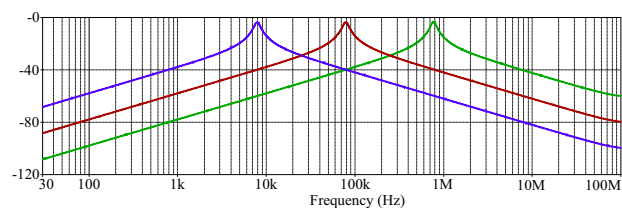


Figure 10. Simulated BP response for three different capacitance values.

4 Conclusion

In this paper, the three inputs single output voltage mode filter topology employing the commercially available IC, LT1228 is proposed. The presented filter employs only single LT1228, single resistor and two capacitors. It

doesn't require passive or active component matching condition to obtain desired filter responses. Also, the selection of filter response can be done without the requirement of double gain amplifier. The natural frequency and quality factor can be tuned electronically. If value of C_1 and C_2 is simultaneously adjusted, the natural frequency can be tuned without affecting quality factor as analyzed in Eq. (10). The PSpice simulation results using macro-model of LT1228 are agree well with theory anticipation. The proposed filter is considered as simple circuit because it uses only single commercially available IC. However, the voltage buffer is required for cascading and the tune of quality factor cannot be adjusted without affecting the natural frequency.

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