# MULTIFUNCTIONAL TUNABLE FILTER WITH OTA

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## ABSTRACT

This paper deals with electronically tunable multifunctional second order filter at frequency 1 MHz. The operational transconductance amplifier (OTA) is used as an active device. OTA is very suitable for various electronic control implementations. Frequency and quality of a pole can be set. The filter works in the voltage mode. There are realized three types of the transfer functions on the outputs – high pass (HP), low pass (LP) and band pass (BP). OTA LT1228 (Linear Technology) has been chosen for the final implementation and verification.

## 1. INTRODUCTION

The category of the multifunctional filters is universal due to more outputs. The possibility of electronic control of a pole frequency ($f_P$) and a pole quality ($Q_P$) is the next advantage, because the controlling can be digitalized. Operational transconductance amplifier is very available for electronic control. The great advantage of these filters with this active component is controlling by change of transconductance through driving current. The disadvantage of the OTA is small input dynamic range. It can be bring in a few tens of mV into their differential inputs for an acceptable distortion [1]. Small dynamic range has to be increase for practical realization. It can be done by adding voltage dividers to OTA's inputs. This modification requires that the inputs voltage dividers have to be isolated by voltage followers.

## 2. DESCRIPTION AND DESIGN OF THE FILTER

The basic structure of the filter comes from [2] – see figure 1(a). The filter can work in voltage and current mode. This paper provides a description of the voltage mode. Filter has one common input and three outputs with transfer functions LP, HP and BP. Input voltage dividers and voltage followers were added to the basic structure. The voltage followers separate input dividers. Another modification was removal of one OTA amplifier. This modification has one disadvantage which is a low value of the transfer function at the output of the HP. This value is approximately equal to the ratio of division of input dividers. Modified structure of the filter is shown in figure 1. The filter will be designed for the pole frequency $f_P$ = 1 MHz. This pole frequency is far too high and it is getting near to the limits of current OTA amplifiers. The

LT1228 OTA provides one of the largest bandwidth available on the market today and this is the reason why it was selected.

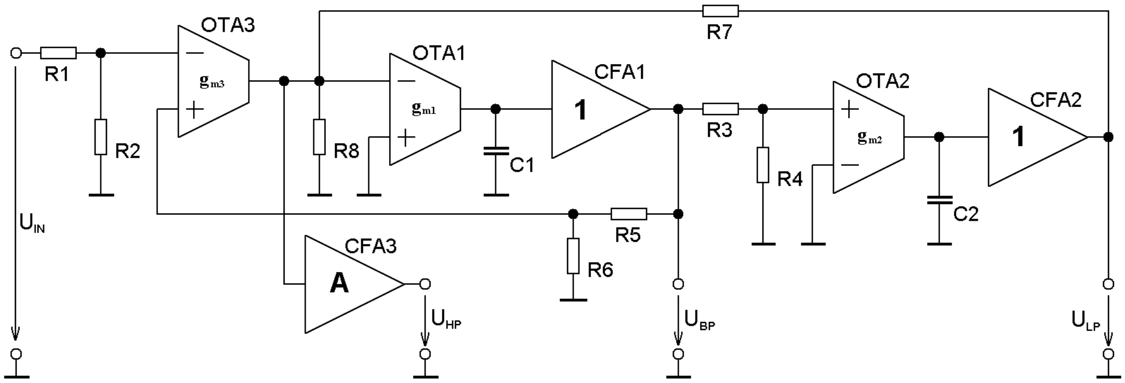


**Figure 1:** Modified filter design.

Transfer functions of voltage dividers (1) [3] and all three transfer functions (2, 3, 4) are:

$$k_1 = R_2 / (R_1 + R_2),\ k_2 = R_4 / (R_3 + R_4),\ k_3 = R_8 / (R_7 + R_8),\ \ k_4 = R_6 / (R_5 + R_6), \quad (1)$$

$$K_{LP}(p) = \frac{\frac{g_{m1} \cdot g_{m2} \cdot g_{m3} \cdot R_7}{C_1 \cdot C_2} \cdot k_1 \cdot k_2 \cdot k_3}{D(p)},\ K_{BP}(p) = \frac{p \cdot \frac{g_{m1} \cdot g_{m3} \cdot R_7}{C_1} \cdot k_1 \cdot k_3}{D(p)}, \quad (2, 3)$$

$$K_{HP}(p) = \frac{-p^2 \cdot g_{m3} \cdot R_7 \cdot k_1 \cdot k_3 \cdot A}{D(p)}. \quad (4)$$

The common denominator is

$$D(p) = p^2 + p \cdot \frac{g_{m1} \cdot g_{m3} \cdot R_7}{C_1} \cdot k_3 \cdot k_4 + \frac{g_{m1} \cdot g_{m2}}{C_1 \cdot C_2} \cdot k_2 \cdot k_3. \quad (5)$$

The formulae for frequency and quality of pole are ($g_{m1} = g_{m2} = g_m$ and $C_1 = C_2 = C$)

$$\omega_p = \frac{g_m}{C} \cdot \sqrt{k_2 \cdot k_3},\ \ Q_p = \frac{1}{g_{m3} \cdot R_7 \cdot k_4} \cdot \sqrt{\frac{k_2}{k_3}}. \quad (6, 7)$$

Values of transfers in pass-bands are

$$K_{\max BP} = k_1 / k_4,\ K_{0LP} = g_{m3} \cdot R_7 \cdot k_1,\ K_{0HP} = -g_{m3} \cdot R_7 \cdot k_1 \cdot k_3 \cdot A. \quad (8, 9, 10)$$

The basic parameters of the filter can be controlled by change of $g_m$ and $g_{m3}$ as we can see from previous formulae. The quality of the pole can be changed by $g_{m3}$ independently on the frequency of the pole. But transfer functions of the LP and HP are changed due to the $g_{m3}$ (9,10). Parameters for the filter design are: $f_P$ = 1 MHz and $Q_P$ = 1.

Values of resistors are $R_1 = R_3 = R_5 = R_7$ = 3300 Ω and $R_2 = R_4 = R_6 = R_8$ = 100 Ω for selected ratio of division $k_1 = k_2 = k_3$ = 1/34. The capacity $C$ = 47pF (E6) is chosen. $g_m = g_{m1} = g_{m2}$ = 10,04 mS are calculated from formula (6). $g_{m3}$ = 10,3 mS is calculated from formula (7) for $Q_P$ = 1. It is necessary to decrease the transconductance for setting lower $f_P$ and higher $Q_P$. This condition is useful for real realization. The transfer functions of outputs calculated form formulae (8 - 10) are $K_{\max BP} = 1$, $K_{0LP} \doteq 1$, $K_{0HP} = -0{,}029 \cdot A$. Here, we can see a low transfer value at HP related with the ratio of division of the voltage dividers.

## 3. ELECTRONIC CONTROL

Integrated circuit LT1228 includes transconductance operational amplifier and current feedback amplifier (CFA) in one case. The CFA can be used as the voltage follower. The transconductance of the OTA (LT1228) is set by driving current ($I_{SET}$) calculated from the equation $g_m = h \cdot I_{SET}$ [4]. Transconductance depends on the loading capacitance, this fact has not been mentioned in [4]. Parameter $h$ = 10 for resistive load ($g_{m3}$), but for capacitive load is $h$ different as shown in [3]. Parameter $h$ = 8,8 for $C$ = 47 pF ($g_{m1}$, $g_{m2}$). The driving currents, for calculated $g_m$ and $g_{m3}$, are $I_{SET1} = I_{SET2}$ = 1,14 mA and $I_{SET3}$ = 1,03 mA.

Next relations show example of values of $I_{SET}$ for filter's parameters change:

$f_P \in \langle 100 \text{ kHz}; 1 \text{ MHz}\rangle \Rightarrow I_{SET1} = I_{SET2} \in \langle 114\ \mu\text{A}; 1{,}14 \text{ mA}\rangle$,

$Q_P \in \langle 1; 10\rangle \Rightarrow I_{SET3} \in \langle 1{,}03 \text{ mA}; 103\ \mu\text{A}\rangle$.

The CFAs, which are part of the LT1228 circuit, are used as voltage followers. The input of the CFA is internally connected to OTA's output. There is only required to set the feedback for the CFA function as voltage followers with gain 1. The feedback is realized by connection of feedback resistor $R_F$ = 1 kΩ. The CFA3 of OTA3 is not used (output of HP). A signal is taken out directly from OTA3's output. Because of that, this CFA can be used for separation and amplifying of the signal at HP's output. The separation of this output is necessary, because the parallel connection of any impedance to resistor $R_8$ can influence all transfer functions. The amplification A (CFA3) is equal to reciprocal value of the transfer function in pass-band of HP. The value of the gain is rather high so the bandwidth is lower. It is necessary to use external amplifier with higher bandwidth for better parameters achievement. The design is done only for possibility of amplifying HP's output in this paper.

## 4. REALIZATION AND MEASUREMENT RESULTS

The filter was realized as a laboratory sample for the function validation. The design is almost the same as shown in figure 1 with a few changes related to the practical realization. The results of measurement are shown in figures 2 and 3. Figure 2 includes the corresponding simulation for comparison. There are differences at outputs of HP and BP. Limitation of the maximal attenuation at low frequencies is most likely to cause by parameter of OTA, which is not considered even in professional model of this circuit. The maximal attenuation at low frequencies of HP and BP is influenced by the value of output resistance $R_{OUT}$. This behavior was observed on the basis of the analysis of the OTA input and output impedance. The maximal attenuation of the filter is higher for higher value of $R_{OUT}$. The manufacturer states in [4] the range of the output resistance from 2 MΩ to 8 MΩ. The real circuit will have instead lower value of this parameter. The attenuation of the filter at low frequencies will higher in case of higher value of this parameter in model and limitation of attenuation start at lower frequencies. The limitation of attenuation, for simulated characteristics depicted in figure 2, starts for BP at frequency $f \cong 1$ Hz and for HP at frequency $f \cong 0{,}1$ Hz. The difference at high frequencies for HP is caused by compensating capacitor of amplifier with CFA3 on HP's output. The value of capacitor affects the curve of module characteristic in its fold region upon the frequency of the pole. The value of capacitor was determined by the simulation. Real circuit has different parameters than its model. Because it is for compensation parasitic parameters, it was necessary to tune its value by experimental measurement. The higher value of transfer function for HP and LP in pass-band is probably related to tolerance of parts.

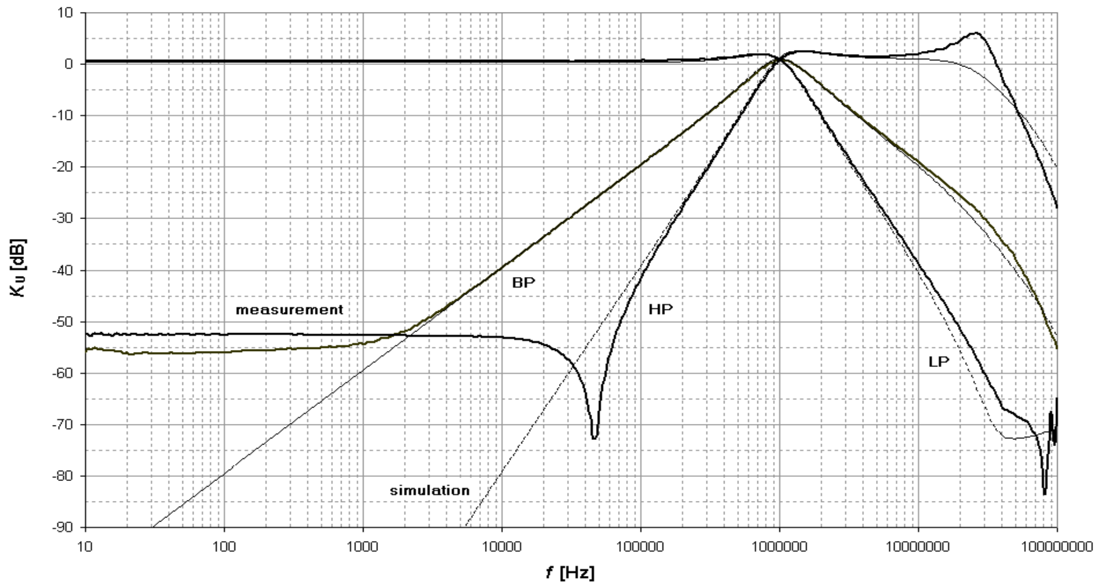


**Figure 2:** Measured and simulated module frequency characteristic for $f_P$ = 1 MHz, $Q_P$ = 1.

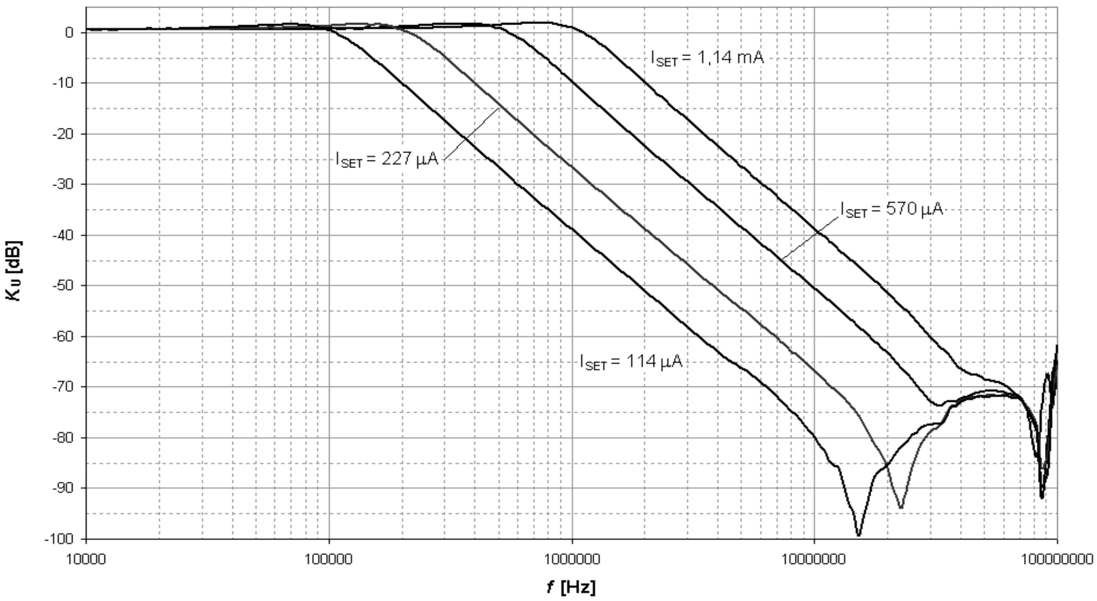


**Figure 3:** Measured module frequency characteristic with different $f_P$ setting.

Figure 3 shows retuning of the pole frequency through the driving current $I_{SET}$ to OTA1 and OTA2. There is only a little difference at high frequencies in maximal attenuation region (LP). The values of $I_{SET}$ are printed in figure. The corresponding pole's frequencies are $f_P$ = (0,1; 0,2; 0,5; 1) MHz. The deviation of the frequency of the pole is caused by accuracy of driving current setting and by parasitic parameters of the OTA.

Simulations and measurements have proved that frequency of a pole of the OTA ($f_{POTA}$) affects maximal value of the $Q_P$. As mentioned, $f_P$ = 1 MHz is high enough. $f_{POTA}$ is insufficient for higher values of the $Q_P$. Thereby the value of the maximal transfer in the pass-band of the PP increases (it is higher than 1) and the change of the $Q_P$ does not conform to the formula (7). $f_{POTA}$ limits maximal obtainable value of the $Q_P$ and value of $g_{m3}$ should not decrease less then 900µS for LT1228 ($f_P$ = 1 MHz). Lower value may cause instability of the filter. However it is not possible to specify an explicit dependence between $g_{m3}$ and $Q_P$ for this case. Value of transfer in the pass-band of PP and values of the $Q_P$ correspond with calculations (7, 8) for $f_P$ lower than 100 kHz. The maximal value of the $Q_P$ is also limited but reaches to higher values than $f_P$ set to a higher value. In order to reach a better class when $f_P$ = 1 MHz it would be sufficient to use OTA with larger band width so that the characters correspond to introduced dependences.

## 5. CONCLUSION

The multifunctional second order filter with three OTAs at frequency 1 MHz is presented in this paper. The main advantage of the filter is possibility of electronic controlling of the frequency and quality of the pole. There were derived the transfer functions for outputs and performed the design. The most important parameter is OTA's band width. The main influence of this parameter is limiting of maximal value of the $Q_P$ at higher frequencies. Parameters of the LT1228 are not sufficient enough for high values of the $Q_P$ at $f_P$ = 1 MHz. The LT1228 was chosen for function verification. The results of the measurement correspond with simulations and confirm the theory. There were only small deviations which were described.

## ACKNOWLEDGMENT

This research has been supported by the Research programs of Brno University of Technology MSM21630513 and by the Grant Agency of the Czech Republic under contracts No. 102/08/H027.

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