# MULTIFUNCTIONAL BIQUAD WITH ELECTRONIC ADJUSTABLE PARAMETERS

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## ABSTRACT

Design of the multifunctional high pass (HP), band pass (BP) and low pass (LP) biquadratic active filter with the operational transconductance amplifiers (OTAs) in the hybrid mode is presented in this paper. The circuit is discussed (electronic tuning, electronic adjusting quality $Q$ and sensitivities). Simulations in PSpice and experimental results are presented.

## 1. INTRODUCTION

Some modern integrated active blocks have possibility to electronic control of his parameters. It is possible to used this principle on adjustable filters and oscillators. One typical is the operational transconductance amplifier (OTA).

## 2. CIRCUIT DESIGN

Second-order multifunctional filter [1] with OTAs and buffers is shown in Fig. 1. Circuit diagram was designed with an electronic control of the characteristic (cut-off) frequency and the quality factor ($Q$). This biquad is based on the well know [1] KHN type. There the OTA as voltage to current converter is used instead classical summator with the OA, where summation can be easy obtained by node and KCL only. Denominator of the transfer function is

$$D(s) = s^2 + \frac{\omega}{Q}s + \omega^2 = s^2 + \frac{g_1 g_3 M^2 R}{C_1}s + \frac{g_1 g_2 g_4 M^3 R}{C_1 C_2}. \quad (1)$$

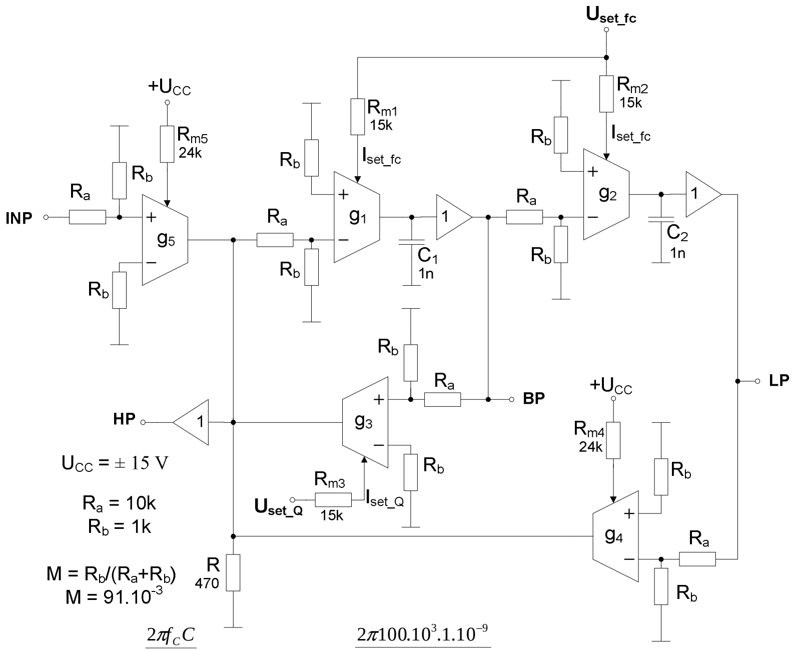
The transfer functions are

$$K_{HP}(s) = \frac{g_5 M R s^2}{D(s)},\ K_{BP}(s) = \frac{\frac{g_5 M^2 R g_1}{C_1}s}{D(s)},\ K_{LP}(s) = \frac{\frac{g_5 M^3 R g_1 g_2}{C_1 C_2}}{D(s)}. \quad (2), (3), (4)$$

The characteristic frequency ($f_C$) and the quality factor ($Q$) are (if $C_1 = C_2 = C$, $g_1 = g_2 = g$)

$$f_c = \frac{g\sqrt{g_4 R.M}.M}{2\pi C},\ Q = \frac{\sqrt{R g_4 M}}{g_3 R.M}. \quad (5), (6)$$

The values of the passive elements and the parameters were designed on $f_C$ = 100 kHz and $Q$ = 1. The resistors in divider on the input OTA are [2] $R_a$ = 10 kΩ, $R_b$ = 1 kΩ. The voltage transfer functions OTAs to the summing node are $R.g_3.M = R.g_4.M = R.g_5.M = 1$. The value $R$ was selected 470 Ω with respects practical available values of the $g_m$ common OTAs. After are $g_5 = g_4 = g_3 = 1/(R.M) = 1/(470.91.10^{-3}) = 23,4$ mS.




$$U_{SET\_fc} = \frac{\frac{2\pi f_C C}{M}}{19,2}.R_{m1} - \left|U_{CC}^-\right| + 1,4 = \frac{\frac{2\pi 100.10^3.1.10^{-9}}{91.10^{-3}}}{19,2}.15.10^3 - 15 + 1,4 = -8,2\,V$$

$$U_{SET\_Q} = I_{SET\_Q}.R_{m3} - \left|U_{CC}^-\right| + 1,4 = \frac{23,5.10^{-3}}{19,2}.15.10^3 - 15 + 1,4 = 4,7\,V$$

**Figure 1:** Multifunctional active biquad using OTAs and buffers

Resulting values of $R_{m4}$ and $R_{m5}$ are

$$R_{m4} = R_{m5} = \frac{U_{CC}^+ + \left|U_{CC}^-\right| - 1,4}{I_{SET}} = \frac{U_{CC}^+ + \left|U_{CC}^-\right| - 1,4}{\frac{g_4}{19,2}} = \frac{15 + 15 - 1,4}{\frac{23,4.10^{-3}}{19,2}} = 23,5\,k\Omega. \quad (7)$$

## 3. SIMULATIONS, ANALYSIS AND EXPERIMENTAL RESULTS

The circuit in Fig. 1 was simulated in PSpice with using professional macro models LM 13700 [2] and measured on a solderless connecting field. The results are in Fig. 2. The sensitivities of $f_C$ on changes passive circuit elements (numerical PSpice Advanced Analysis) are by elements $C_1$, $C_2$ near -0,5 and by $R$ near 0,5. The values of the sensitivities from 0,3 to 0,5 (without respect sign) have resistors on input OTAs and resistors to the current control pin OTAs. Grounded resistors (unusable input OTAs) have the minimum values sensitivities (under 0,01). The sensitivities of $Q$ on changes passive elements are about 0,5, but sensitivities on $R_{m3}$ and resistors in divider by OTA with control $Q$ ($g_3$) even values near 0,8. Dispersion of the characteristic frequency (PSpice Monte Carlo, tolerance 1% by all resistors and 5% by capacitors) is circa ± 3,6 kHz (from nominal 95 kHz). There an electronic tuning (by simulation, Fig. 3) is possible in the interval from 200 Hz to 390 kHz ($U_{SET\_fc}$ in supply voltage range circa from -13,9 V to 15 V), practical to 200 kHz. Similarly the change of the $Q$ can be (simulation) from 0,7 to 60, practical tested from 0,8 to 4 (incomplete interval of control voltage, and used generator without fine setting frequency). The maximum input voltage level is around 500 mV (RMS), above 500 mV is signal distortion (no limitation). The transconductance $g_5$ allows electronic adjusting of the basic transfer namely $K_0$.

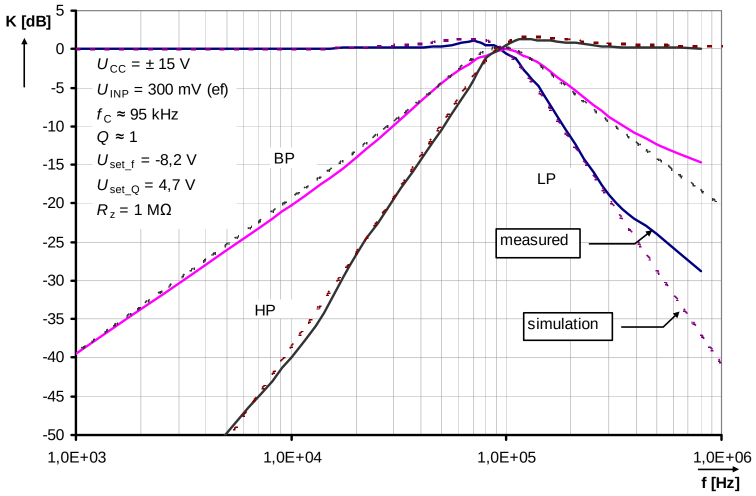



**Figure 2:** Magnitude responses of the biquad (simulation and measurement)

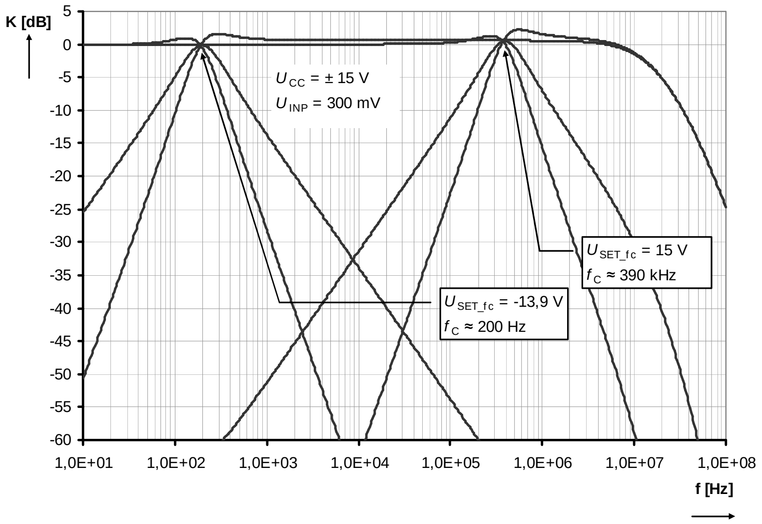



**Figure 3:** Electronic tuning of the biquad (simulation)

## 4. CONCLUSION

There was shown design of the multifunctional active biquad with OTAs. Advantages are electronic tuning and electronic adjustable *Q*. This filter has quite small sensitivities on passive elements. Disadvantage is even five active blocks (OTA), when it is possible realized filter with the similar transfer features only with three active blocks [3].

## 5. REFERENCES


[1] DOSTÁL, T.: High Frequency State-variable Biquadratic Active Filters. Radioengineering 1998, vol. 7, No. 1, s. 1-6.

[2] National Semiconductors. Dual Operational Transconductance Amplifiers with Linearizing Diodes and Buffers LM 13700. 2004. 26 s. http://www.national.com/

[3] DOSTÁL, T.; ŠOTNER, R.: Multifunctional tuned second-order ARC filter with commercially available transconductors. In *Proceedings of 17th International Conference Radioelektronika 2007*. Brno: Dep. of Radio Electronics, Brno University of Technology, 2007. s. 389-392. ISBN: 1-4244-0821-0