Controlled filters with LT1228 OTA amplifiers

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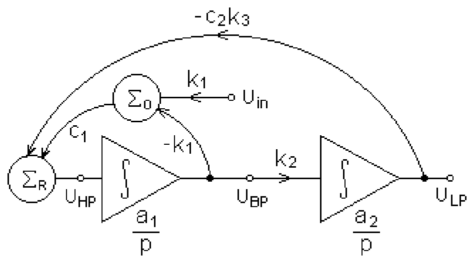
Abstract: *Fast OTA amplifiers LT1228 are presently available. Their transconductance can be controlled continuously by an auxiliary current. This opens up interesting possibilities of discrete realizations of active filters with electronically controlled parameters in the frequency band of about 1MHz.*

Introduction

The development of new integrated technologies brings interesting circuit elements that are suitable for the construction of active filters. The *LT1228* integrated circuit by *Linear Technology* is one of these elements [1]. This circuit consists of two independent subcircuits: the *OTA* (Operational Transconductance Amplifier), whose transconductance g_m can be controlled by current I_{SET}, and the *CFA* (Current Feedback Amplifier), which can be used e.g. as buffer. Below we show the design procedure of a 2nd order bandpass filter which is tunable within 100Hz-100kHz and has an independently controlled quality factor Q. Since the integrator is realized by means of *OTA* very simply by connecting a capacitor to the *OTA* output, we advantageously use the circuit structure "two integrators in the feedback loop".

Tunable bandpass filter with independent Q control

The circuit structure in Fig. 1 has outputs in the nodes designated U_{HP}, U_{BP}, U_{LP} (high/ band/lowpass filter). The corresponding voltage transfer functions are as follows:



$$K_{HP}(p) = \frac{U_{HP}}{U_{in}} = \frac{c_1 k_1 p^2}{D} = \frac{K_0^H p^2}{D} \tag{1}$$

$$K_{BP}(p) = \frac{U_{BP}}{U_{in}} = \frac{p a_1 c_1 k_1}{D} = \frac{K_0^B \,\omega_0/Q\, p}{D} \tag{2}$$

$$K_{LP}(p) = \frac{U_{LP}}{U_{in}} = \frac{a_1 a_2 c_1 k_1 k_2}{D} = \frac{K_0^L \omega_0^2}{D} \tag{3}$$

$$D = p^2 + p a_1 c_1 k_1 + a_1 a_2 c_2 k_2 k_3 = p^2 + p\frac{\omega_0}{Q} + \omega_0^2 . \tag{4}$$

One possible implementation is shown in Fig. 2. Two types of summators are used. The first summator is realized by the inputs of *OTA3*. The output currents of *OTA3* and *OTA4* flow through resistor R_9. The summing voltage of R_9 represents the output of the second summator.

The voltage transfers of voltage dividers are

$$k_1 = R_2/(R_1+R_2) = R_4/(R_3+R_4),\ k_2 = R_6/(R_5+R_6),\ k_3 = R_8/(R_7+R_8). \tag{5}$$

Coefficients a_1, a_2, c_1, c_2 from Equations (1)-(4) are given by the formulae

$$a_1 = g_{m1}/C_1,\ a_2 = g_{m2}/C_2,\ c_1 = g_{m3}R_9,\ c_2 = g_{m4}R_9. \tag{6}$$

Thus, coefficients c_1, c_2 can be controlled by currents I_{SET3} and I_{SET4}, respectively.

Taking into account the above equations and considering the conditions $g_{m1} = g_{m2} = g_m$ and $C_1 = C_2 = C$ yield formulae for the filter parameters:

$$\omega_0 = \frac{g_m}{C}\sqrt{g_{m4}R_9 k_2 k_3},\ Q = \frac{1}{g_{m3}k_1}\sqrt{\frac{g_{m4}k_2 k_3}{R_9}},\ B = \frac{\omega_0}{Q} = \frac{g_m}{C} g_{m3} R_9 k_1, \tag{7}$$

$$K_0^B = 1,\ K_0^L = \frac{g_{m3}k_1}{g_{m4}k_3},\ K_0^H = g_{m3}R_9k_1 . \tag{8}$$

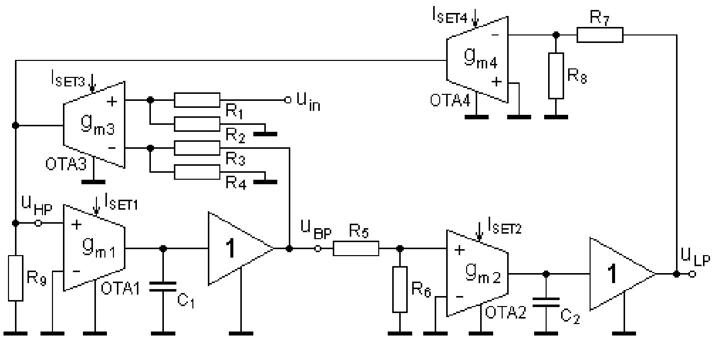


Fig. 2. Designed tunable bandpass filter with independent Q - control.

It should be mentioned that Q can be controlled by means of g_{m3} without modifying central frequency f_0. The frequency can be changed independently by changing simultaneously g_{m1} and g_{m2}.

Design algorithm and design example of tunable bandpass filter from Fig. 2.

<u>Filter parameters:</u>
Frequency range of tuning f_0:= 100Hz - 100kHz.
Range of Q setting: 1 to 80.
Peak-to-peak amplitude of input voltage: $2V_{p\text{-}p}$.

1. Let us introduce symbol K_{max} to notate maximum transfer from the filter input to the input of an arbitrary *OTA*. In the case of *OTAs* used and peak-to-peak input amplitude, we choose K_{max} = 1/34. Then the signal distortion should not exceed the value of 0.1% [1].
2. Transfer k_1 of voltage divider must be chosen with regard to the required value of input voltage. We choose $k_1 = K_{max}$ and also $k_2 = K_{max}$ too, because $K_0^B = 1$.
3. The maximum transfer of a lowpass/highpass filter is Q-times higher than the transfer of low/high-frequency components. In the course of the design, we have to consider the optimization of dynamic range and the values of input voltages of individual *OTAs*. For the above reasons, we have to fulfill equality $K_0^L Qk_3 = K_{\max}$. Substituting (8) instead of K_0^L yields the condition
$$g_{m4} = Qg_{m3} \tag{9}$$
The condition $K_0^H Q = K_{\max}$ has to be satisfied. Substituting (8) instead of K_0^H yields
$$Qg_{m3}R_9 = 1 \tag{10}$$
Furthermore, we find readily that $k_3=(k_1/k_2)^2 = K_{max}$.
4. Condition $R_9 g_{m4}$=1 results from (9) and (10). We choose transconductance g_{m4} to fulfill condition (9) with the *OTAs* applied. If we choose g_{m4} = 10mS, then R_9 = 100Ω.
5. We compute g_{m3} from (9) for the bottom value Q = 1:
$$g_{m3} = g_{m4}/Q = 10mS .$$
It is the maximum g_m that can be realized by the given *OTAs*. Lowering g_{m3} towards the value of 10/80 = 0.125mS increases Q from 1 to 80.
6. C is computed from (7):
$$C = \frac{g_{md}}{2\pi f_{0d}}\sqrt{g_{m4}R_9k_2k_3} = \frac{10^{-5}}{2\pi 100}\sqrt{10x10^{-3}x100x1/34x1/34} = 468pF .$$

7. We design the controlling currents I_{SET} of individual *OTAs*.
   The currents of *OTA3* and *OTA4* can be obtained from the equation $g_m = h.I_{SET}$, where h =10 is valid for the LT1228 [1]:

   $$I_{SET3} = g_{m3} / h = (0.125x10^{-3} \div 10x10^{-3})/10 = 12.5\mu A \div 1mA,$$

   $$I_{SET4} = g_{m4} / h = 10x10^{-3} / 10 = 1mA.$$

   For *OTA1* and *OTA2* the catalogue value h = 10 is not valid because the transconductance depends on the loading capacitance. This troublesome feature of LT1228 has not been published. The corresponding graph in Fig. 3 has been obtained experimentally. For our case, we read the real value h = 9.75. Then

   $$I_{SET1} = I_{SET2} = g_m / h = (0,01x10^{-3} \div 10x10^{-3})/9.75 = 1.026\mu A \div 1.026mA.$$

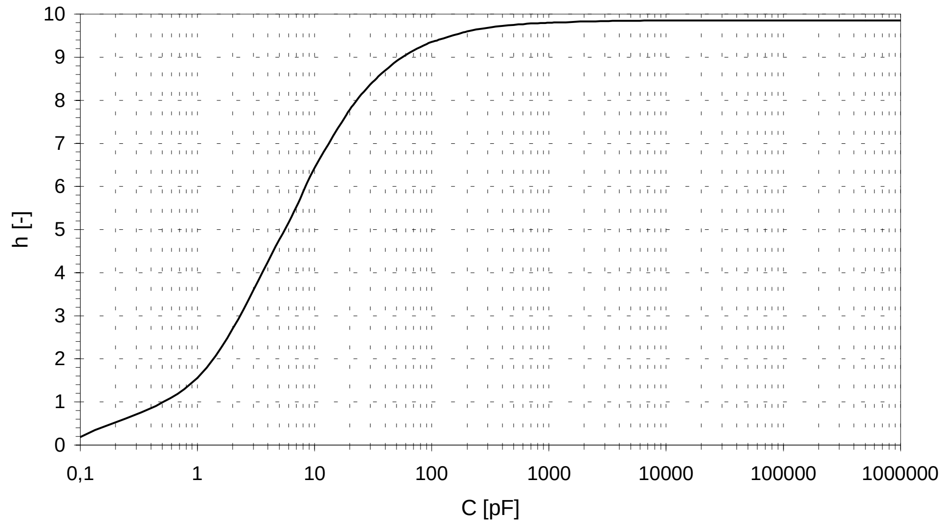


Fig. 3. Dependence of coefficient h on loading capacitance.

8. We design resistors inside the voltage dividers with the transfers k_1, k_2, k_3 from (5):

   $R_1 = R_3 = R_5 = R_7 = 3{,}3\text{k}\Omega$, $R_2 = R_4 = R_6 = R_8 = 100\Omega$.

Experimental verification

Frequency responses were obtained by means of the *HP 4195A* circuit analyzer. Fig. 4 shows the amplitude responses measured for constant quality factor and electronic tuning (Fig. *a*), and for constant f_0 and controlled Q or B (Fig. *b*). These results are consistent with the *SPICE* computer simulation.

The measurement has demonstrated that it is necessary to choose carefully the value of feedback resistor R_F [1], which is part of the buffer realized from the internal *CFA*. For low values (up to hundreds of ohms), the filter was unstable. We used the value of 1kΩ without problems.

During the measuring, the DC component was observed in the *BP* output. Its value was dependent on controlling current I_{SET}.

Conclusions

In the paper, we propose a method of designing a 2nd - order electronically controlled filter with integrated *OTA* amplifier *LT1228*. The “two integrators in the feedback loop” structure is used.

Experimental measurement disclosed the dependence of OTA transconductance on the value of capacitive load. It is necessary to count with this effect during the design, especially for lower values of capacitances (see Fig. 3).

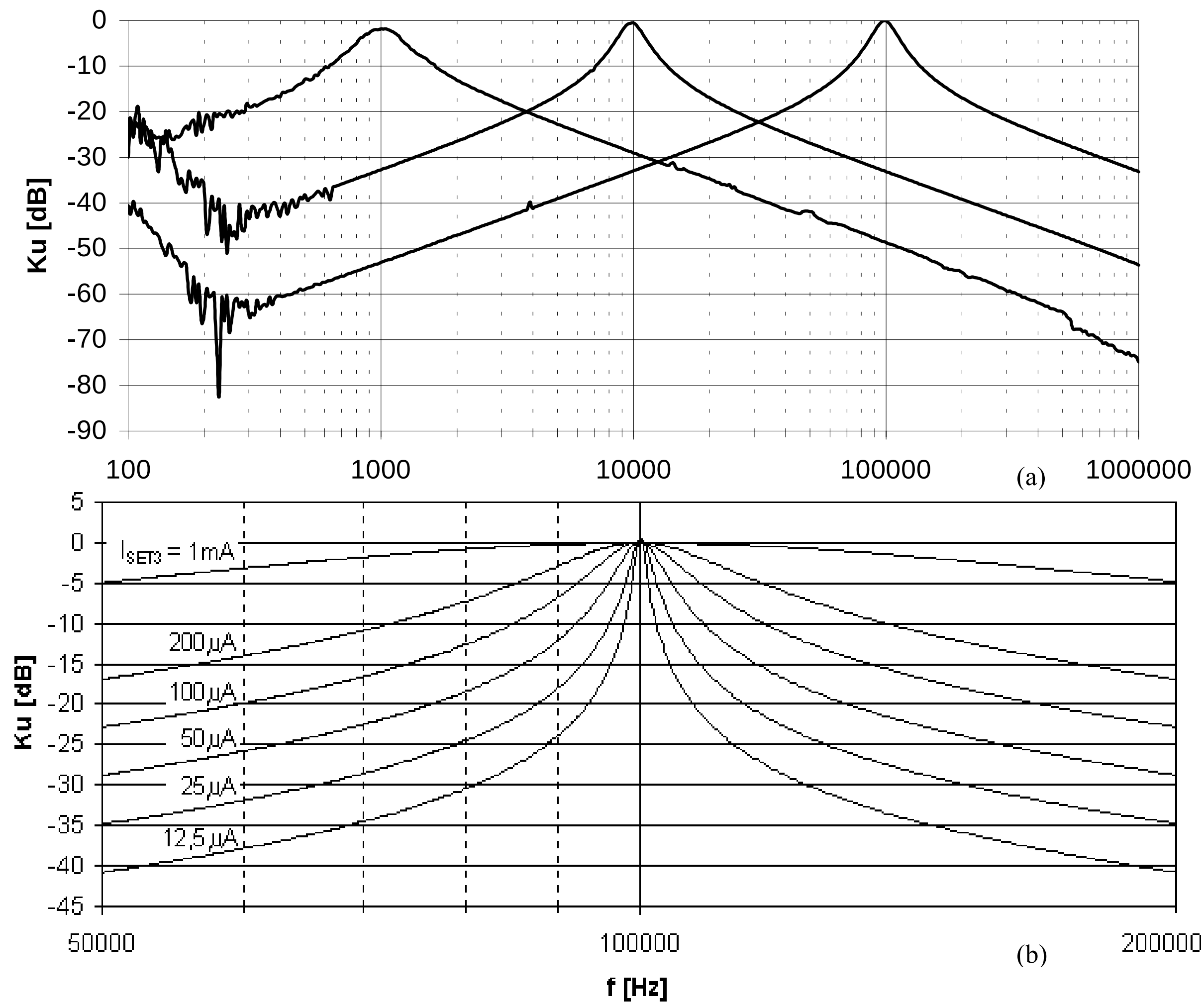


Fig. 4. Frequency responses measured, (a) tuning f_0, Q = 5, I_{SET3} = 0.2mA, (b) controlling Q in values of 1, 5, 10, 20, 40, 80, f_0 = 100kHz, I_{SET} = 1.035mA.

References

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[3] GEIGER, R.L.-SÁNCHEZ, S.E.: Active Filter Design using Operational Transconductance Amplifiers: A Tutorial. IEEE Circuits and Devices Magazine, Vol. 1, No. 2, March, 1985, pp. 20 - 32.

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