ON THE DESIGN OF LOW-FREQUENCY FILTERS USING CMOS OTAs OPERATING IN SUBTHRESHOLD REGION

Abstract : Design considerations on a circuit technique based on subthreshold operation of MOS transistors is described for the realization of low-frequency OTA-C active filters with small capacitance values of the order of 25 pF to 400 pF. Described circuit technique is applied to the α (8-12 Hz), β (13-40 Hz), θ (4-8 Hz), δ (1-4 Hz) band filters for EEG signals. Because of small capacitance values the filter circuit is suitable for the realization on a single VLSI chip using the CMOS technology and enables the user to implement the circuit on implantable biotelemetric applications.

Reference

- G. Düzenli, Y. Kılıç, H. Kuntman and A. Ataman: On the design of low-frequency filters using CMOS OTAs operating in the subthreshold region, Microelectronics Journal, Vol.30, No. 1, pp.45-54, 1999.

Experimental verification

Two different chips were fabricated with TÜBİTAK-YİTAL 3μ technology, one of them includes three OTAs and the other includes four bandpass filters.

The transfer function of the band-pass filter is given by

$$H(s) = \frac{\omega_{P1}^2}{s^2 + \frac{\omega_{P1}}{Q_{P1}} s + \omega_{P1}^2} \frac{s^2}{s^2 + \frac{\omega_{P2}}{Q_{P2}} s + \omega_{P2}^2} \tag{7}$$

Design equations of the band-pass filter are obtained as

$$C_1 = \frac{G_{m1}}{Q_{P1} \cdot \omega_{P1}} \tag{8}$$

$$C_2 = \frac{G_{m2} \cdot Q_{P1}}{\omega_{P1}} \tag{9}$$

$$C_3 = \frac{G_{m3}}{Q_{P2} \cdot \omega_{P2}} \tag{10}$$

$$C_4 = \frac{G_{m4} \cdot Q_{P2}}{\omega_{P2}} \tag{11}$$

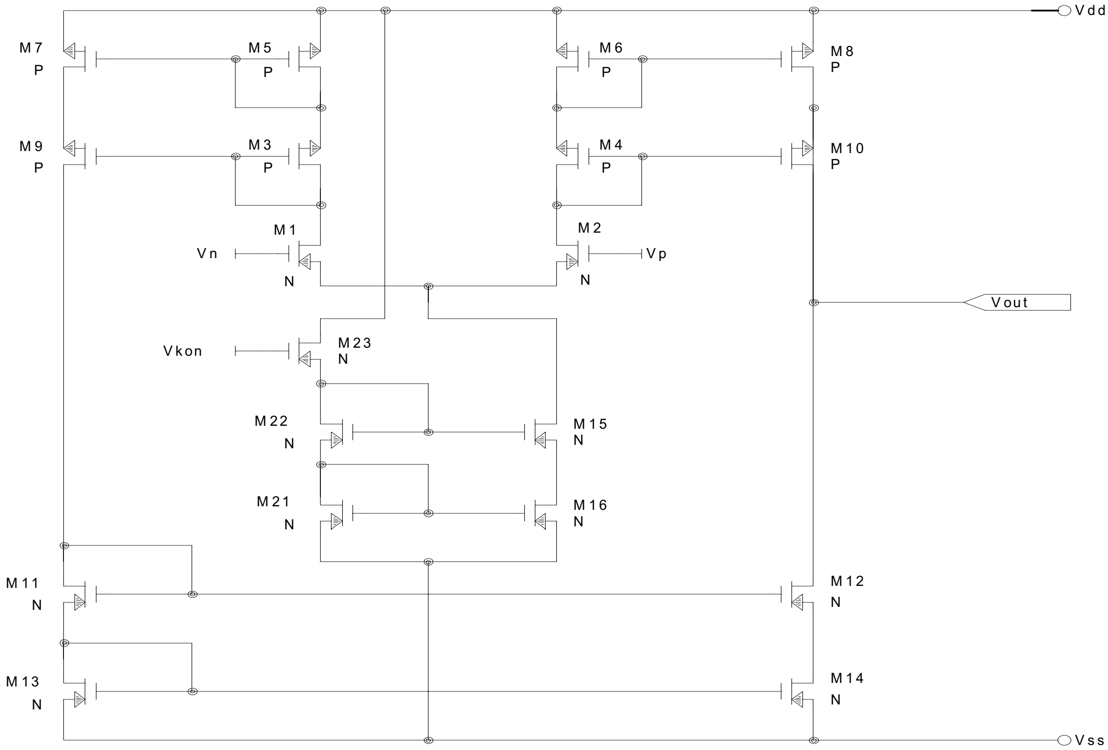

Figure 1 Realized CMOS symmetrical cascode OTA.

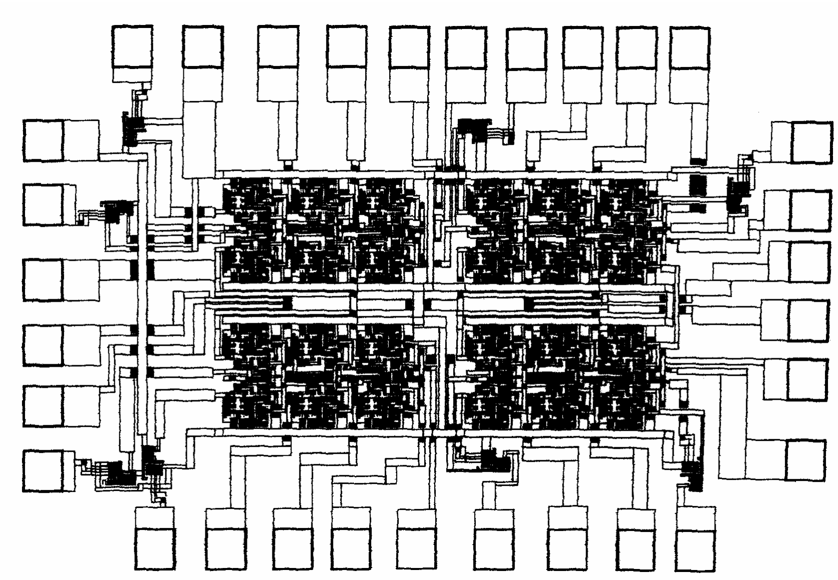

Figure 4. Enlarged top view of the 4 band-pass filters integrated-circuits chip.

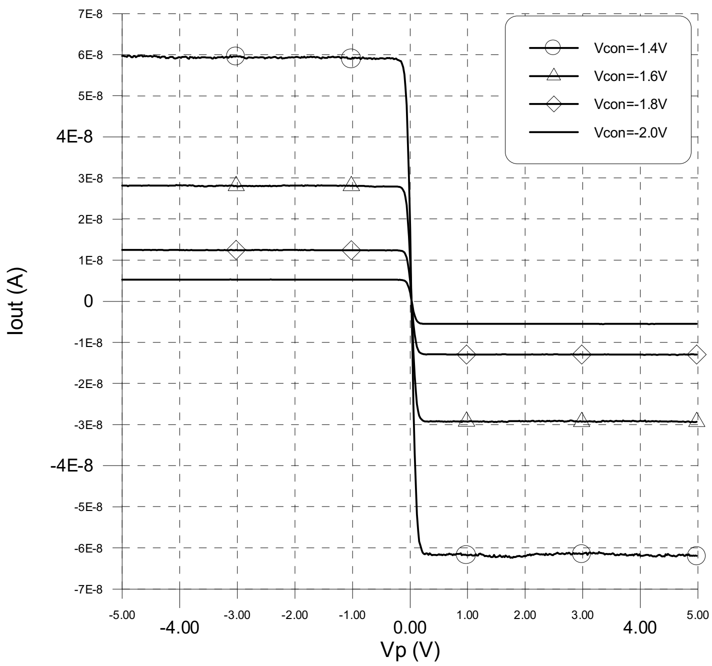

Figure 5. Dependence of OTA output current on input differential voltage for several biasing current values in subthreshold region.

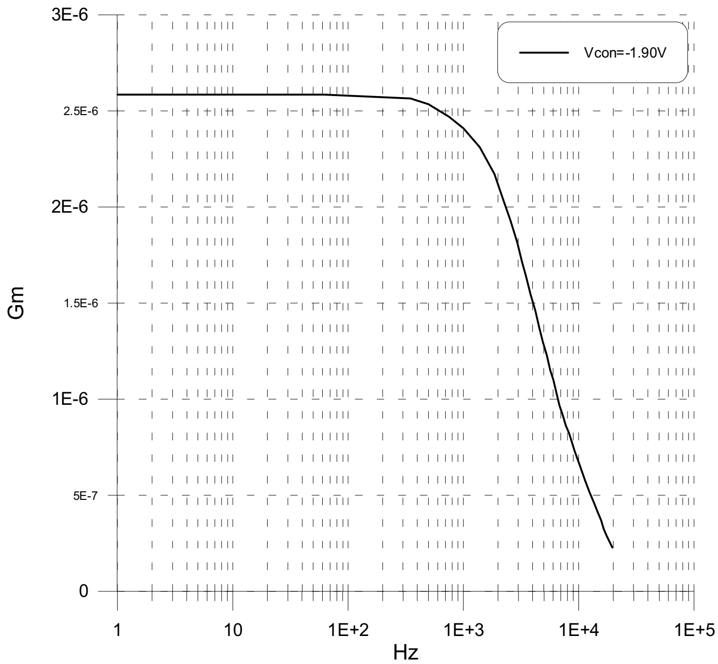

Figure 6. Measured frequency response of the OTA transconductance in subthreshold region

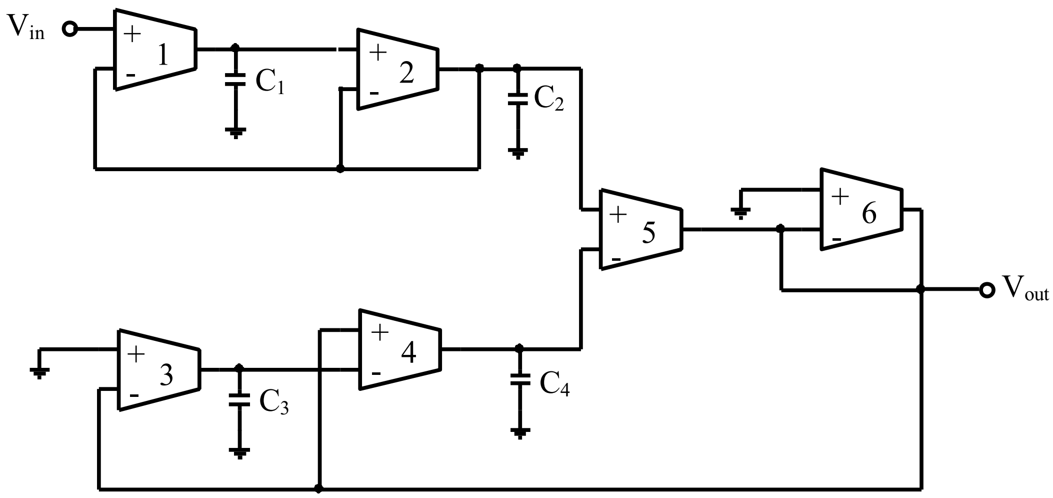

Figure 7. Band-pass filter structure used to realise EEG filters

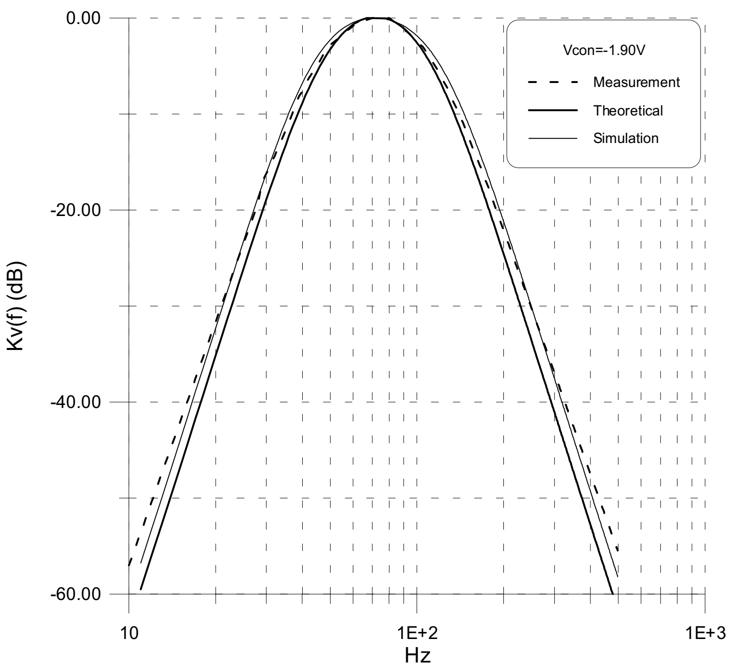

Figure 8. Measured Frequency response of Band-pass OTA-C filter operating in subthreshold region

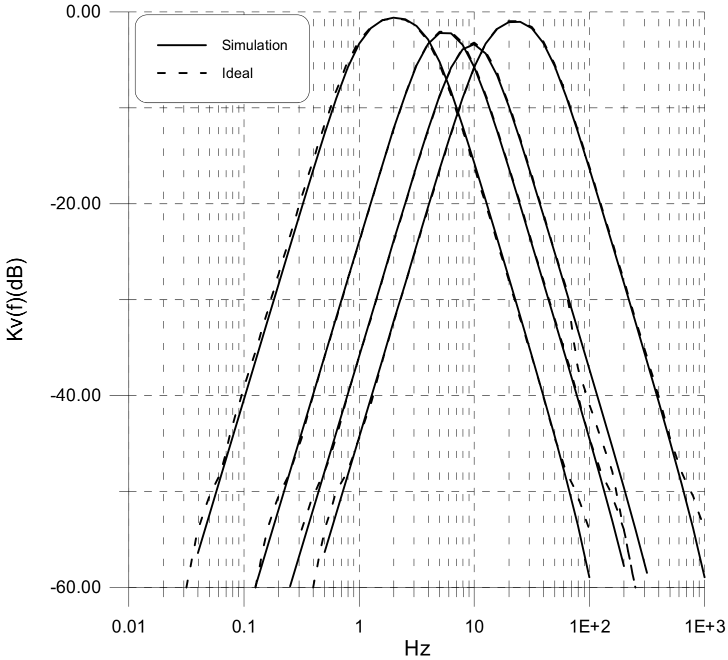

Figure 9. Simulated frequency responses of realized EEG band filters.

Table 2 Dimensions of MOS transistors

	M_1	M_2	M_3	M_4	M_5	M_6	M_7
W(μm)	**5**	**5**	**10**	**10**	**10**	**10**	**10**
L(μm)	**3**	**3**	**3**	**3**	**3**	**3**	**3**
	M_8	M_9	M_{10}	M_{11}	M_{12}	M_{13}	M_{14}
W(μm)	**10**	**10**	**10**	**5**	**5**	**5**	**5**
L(μm)	**3**	**3**	**3**	**3**	**3**	**3**	**3**
	M_{15}	M_{16}	M_{21}	M_{22}	M_{23}		
W(μm)	**5**	**5**	**5**	**5**	**5**		
L(μm)	**3**	**3**	**3**	**3**	**3**		

Table 3 Element values for the α, β, θ and δ bands of the EEG signal

Band	f_{p1} (Hz)	f_{p2} (Hz)	C_1 (pF)	C_2 (pF)	C_3 (pF)	C_4 (pF)	I_b (nA)	G_{mi} (nA/V)
α	12	8	166	81	250	122	0.69	8.8
β	40	13	81	40	250	122	1.125	14.3
θ	8	4	125	61	250	122	0.347	4.4
δ	4	1	62.55	30.6	250	122	0.1	1.1