A Low Voltage Rail-to-rail OPAMP Design for Biomedical Signal Filtering Applications

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Abstract

In this paper, a 1 volt rail-to-rail input range amplifier has been proposed. In the amplifier design, the current driven bulk (CDB) technique is adopted to reduce threshold voltages of input devices to eliminate the conventional dead zone problem. The performance results of the proposed 1 volt low power amplifier are input rail-to-rail with gain at 71dB and CMRR at 100dB. We use the proposed amplifier to implement a low pass filter for biomedical signal applications. Simulation results for an electrocardiograph (ECG) signal are very satisfactory. The total harmonic distortion of the low pass filter is -30dB. Besides, the programmable cut-off frequency of the bio-signal low pass filter is provided for use.

Keywords: low voltage, rail-to-rail, biomedical signal, filter, current driven bulk

1 Introduction

Recording the biomedical signals is one of the challenges in a biomedical electronics detection system, because the biomedical signals have very weak amplitude and low frequency, usually of few milli-volts or less and the frequency below 1 KHz. The biomedical electronics detecting system is shown in figure 1, which consists of electrodes, amplifier, LPF, Sample and Hold (S/H) and ADC.

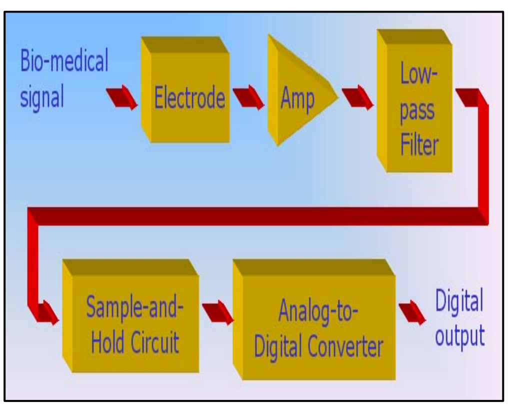

Figure 1: The biomedical electronics detecting system blocks.

Meanwhile, the recording electrodes might pick up many other unneeded interferences. However, the biomedical electronics might be unable to detect small biomedical signals. Therefore, we need a high gain, accurate, and high CMRR amplifier to reduce the common mode noise and to amplify the biomedical signal only [5]. Then, the signal is passed through LPF, S/H and ADC to become a digital signal. After that, these digital data will be processed in PCs or microprocessors. In this paper, a 1 volt rail-to-rail input range amplifier will be achieved by the current driven bulk (CDB) technique. Furthermore, the low pass filter design for biomedical signals is proposed with programmable cut-off frequencies.

2 Design of 1V OPAMP with CDB

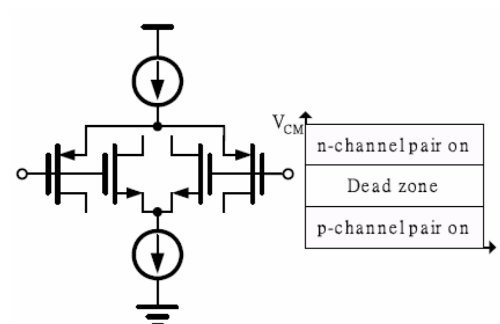

Figure 2: Complementary differential input pairs.

Figure 2 shows conventional complementary differential input pairs [1, 2] that can achieve a rail-to-rail input. But, in a 0.18um CMOS technology the minimum supply voltage is generally limited to about 1.5V. When the supply

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voltage is below Vtn+|Vtp|+Vds,n+|Vds,p|, there is a dead region at the middle of the supply voltage. Therefore, the input common mode range will be limited by both transistor threshold voltages and overdrive voltages.

In this paper, 1V OPAMP design is required that supports a rail to rail input common range. The threshold voltage of an MOS transistor is given as a function of bulk-source voltage V_{BS} , by

$$V_{TH} = V_{TH0} + \gamma(\sqrt{|2\phi_F + V_{SB}|} - \sqrt{|2\phi_F|})$$

where V_{th0} : zero bias threshold voltage, γ: bulk effect factor and φ_F : Fermi potential.

For typical p-channel transistors, $2\varphi_F = -0.7V$, $\gamma = -0.5V^{(1/2)}$, and $V_{th0} = -0.55V$, and a bulk bias V_{BS} is normally larger than 0V, which will increase the threshold voltage. However, by biasing V_{BS} less than 0V we can actually decrease the threshold voltage.

To reduce the threshold voltage as much as possible, we tend to bias the bulk bias | V_{BS} | as high as possible. There is a published method called the current driven bulk (CDB) technique [3] to meet this circuit demand well, as shown in figure 3.

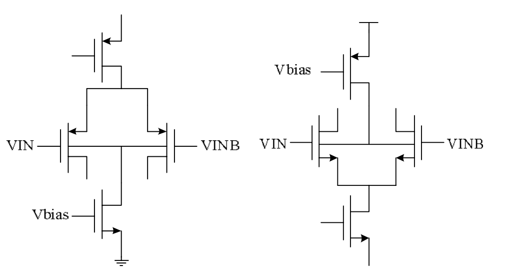

Figure 3: Current driven bulk technique.

To change the voltage of bulk, the voltage of V_{BS} alters that is used to reduce the threshold voltage. Using the current driven bulk technique the threshold voltage can be reduced well under 0.3V in TSMC 0.18um CMOS technology. If $V_{DS}(sat)$ = 0.1V is assumed and designed, an improved operational amplifier with rail-to-rail input range can be achieved for 1V operation. Figure 4 shows a modified single stage amplifier which uses both complementary input pairs and CDB technique.

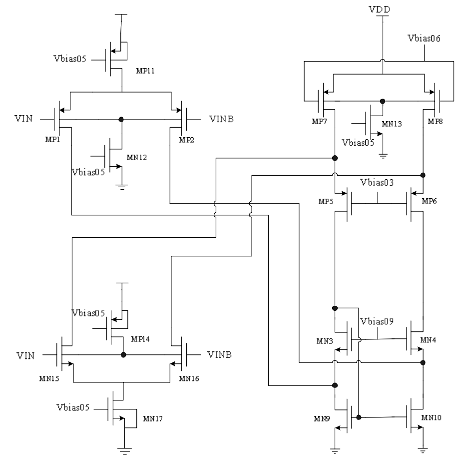

Figure 4: Single stage amplifier with CDB.

3 Simulation Results and Comparison

We first demonstrate the performance of the proposed 1V OPAMP design and then its applications to the low pass filtering of biomedical signals. Figure 5 shows 71dB open loop gain, 78° phase margin and 8 MHz unity gain bandwidth. Note that the designed bandwidth is sufficient for general biomedical signals such as electrocardiograph processing applications.

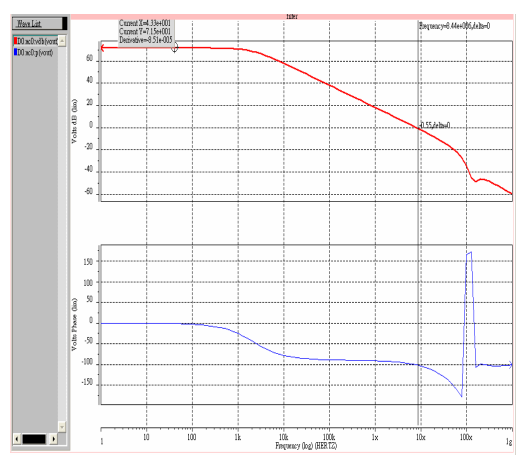

Figure 5: Open loop gain and phase margin.

Figures 6 and 7 show 100dB CMRR and input rail-to-rail feature, respectively. In figure 7, the used input is a full swing square-wave signal with 1V magnitude. The output swing range is from 80mV to 950 mV. This input rail-to-rail feature enables the proposed OPAMP to process the input signal with large magnitude up to 1V.

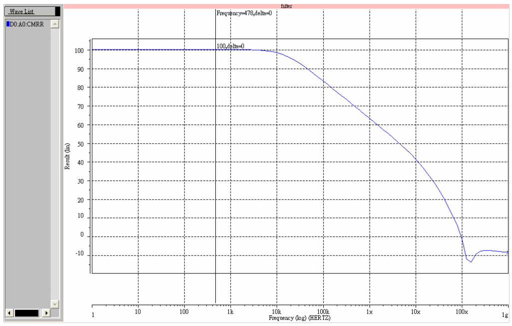

Figure 6: CMRR results (100dB).

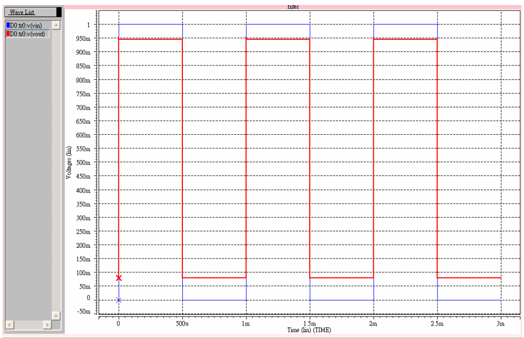

Figure 7: Input rail-to-rail feature.

In Table 1, the performance summary of the proposed design is given with comparison with other prior art circuits. Note that this work shows much less power. Furthermore, for the processing applications of biomedical signals the noise characteristic is of important concern. Our proposed OPAMP design has less noise than those of other circuits. Therefore, the proposed circuit is much more suitable for biomedical applications.

Table1: Comparison summary.

Parameter	This work Post-simulation	[1] Bulk input	[2] Mos level-shift	[4] R level-shift
Supply Voltage	1v	1v	1v	1v
Dc gain(db)	71	70	75	87
Phase margin	78	60	84	61
ICMR	rail-to-rail	--	rail-to-rail	rail-to-rail
Unit-gain Bandwidth	8MHz	190KHz	2.1MHz	1.9MHz
W_{3dB}	2.14kHz	--	--	--
CMRR	100	--	76	62
PSRR+	81	--	69	54
PSRR-	72	--	69	52
Slew rate v/us SR(+)	4.2 v/us	0.15 v/us	3.2 v/us	0.8 v/us
Slew rate v/us SR(-)	5.68 v/us	--	3.9 v/us	1 v/us
Total output noise voltage at 1kHz	143.99u v/rt hz	--	--	--
Equivalent input noise at vin at 1kHz	42.17n v/rt hz	0.19u v/rt hz 在 10kHz	66n v/rt hz	267n v/rt hz
Power dissipation	186.9uW	--	288 uW	--
process	0.18	0.35	0.35	1.2

The design application of a switched-capacitor low pass filter is shown in figure 8. Since the frequency of biomedical signals is very low, if we use R-C for the low pass filter the required resistance and capacitance values will be very large. That is, the area overhead is heavy if the required R-C is implemented in the integrated circuit. Otherwise, the large resistance and capacitance might be realized by external discrete components. But this implementation leads to higher cost and would degrade circuit reliability. Therefore, the switched-capacitor implementation is very suitable for the low pass filtering application of biomedical signals.

We demonstrate the ECG application in figure 9. The used ECG signal has 1Hz frequency while the noise has its frequency of 5 KHz and 0.2V amplitude. The complete input ECG signal is shown in figure 9.

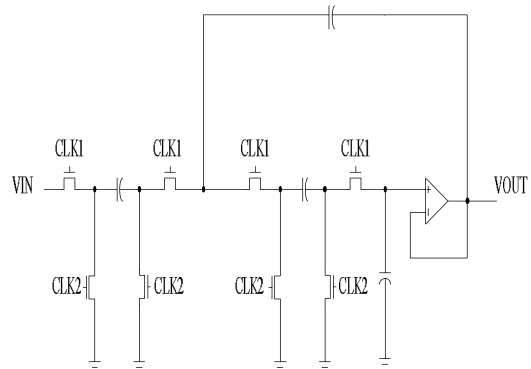

Figure 8: Switched capacitor low-pass filter.

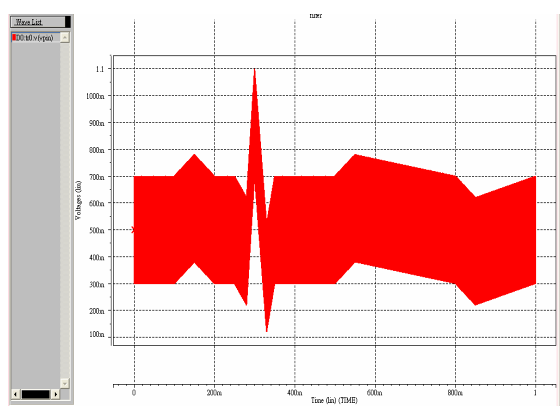

Figure 9: Input ECG signal with noise (5KHz noise with 0.2V amplitude).

The output from the switched-capacitor filter is shown in figure 10. The disturbing noise is well controlled and removed. These results are very satisfactory. As for the performance of the realized low pass filter simulation results of the total harmonic distortion (THD) are performed and given in figure 11. The obtained THD is -30dB for a 250 Hz input with 1V peak-to-peak amplitude.

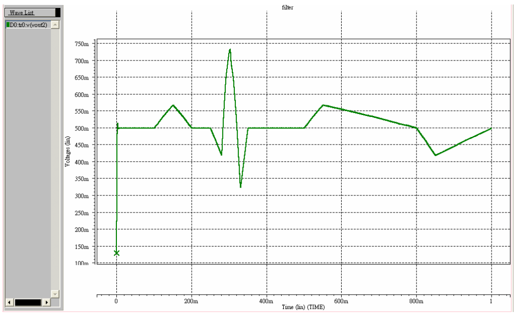

Figure 10: Output ECG without noise.

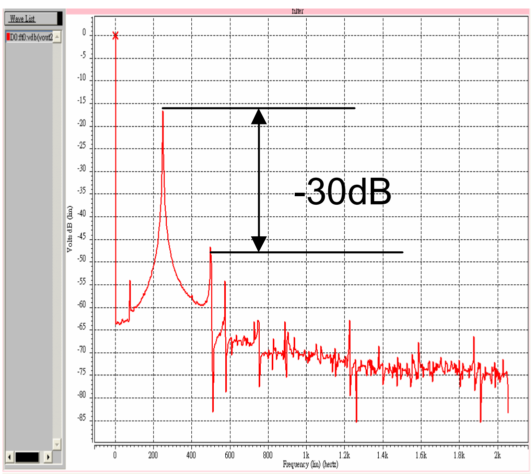

Figure 11: THD of the low pass filter for 1Vp-p input with 250Hz.

To have different cut-off frequencies of the low pass filter, we propose a method to adjust the clock frequency to alter the equivalent resistance. As shown in figure 12, three toggle flip-flops are used as frequency dividers. The final output frequency is controlled by switches a to d. The input signals with both different frequencies and disturbing noise are processed by the proposed filter. The achieved output results without noise are shown in figure 13.

4 Conclusion

In this paper, a 1 volt rail-to-rail input range amplifier has been proposed. In the amplifier

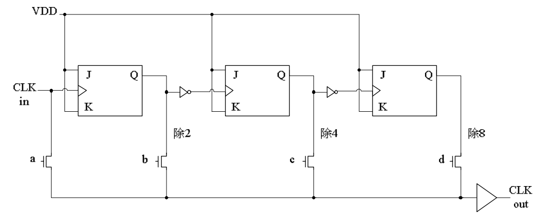

Figure 12: Programmable clock frequency circuit.

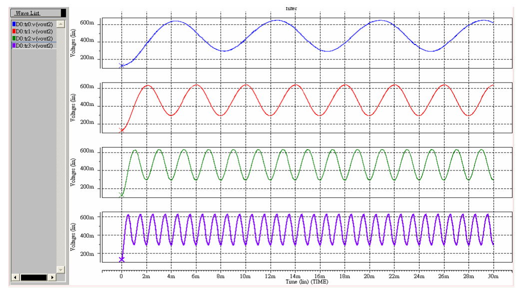

Figure 13: Different cut-off frequency outputs of the low pass filter.

design, the current driven bulk (CDB) technique is adopted to reduce threshold voltages of input devices to eliminate the conventional dead zone problem. The performance results of the proposed 1 volt low power amplifier are input rail-to-rail with gain at 71dB and CMRR at 100dB. We used the proposed amplifier to implement a low pass filter for biomedical signal applications. Simulation results for an electrocardiograph (ECG) signal are very satisfactory. The total harmonic distortion of the low pass filter is -30dB. Besides, the programmable cut-off frequency of the bio-signal low pass filter has been demonstrated.

5 Acknowledgements

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