A High Performance CMOS Opamp and An LP Filter Design Example For Video Applications

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Abstract: - This paper presents a high performance CMOS opamp. The operational amplifier have a rail to rail input and a class-AB rail to rail output stage. The opamp circuit is simulated using the SPICE program and the performance of the opamp is shown on a high order active filter which is suitable for video applications.

Key-Words: - Circuit and System, Active Filters, High Performance Opamp.

1 Introduction

Although in existing CMOS technologies more digital circuits seem to be in the front, analog circuits still keep their importance. Because the signals in the nature are analog and the analog circuits are bridges between digital circuits and the world outside. Moreover, today, analog and digital circuits are fabricated together on the same chip and the design of the analog circuits that can keep up with the high performance of the digital circuits, becomes very imported.

As the technology develops, the versatility of the electronic circuits increases. Opamps, one of the most important analog circuits, have a wide range of use. Therefore, design of opamps has an important place in analog circuit design.

Because of the limitations of the classic opamps and the low performance of the circuits that use those opamps, new circuit structures have been searched and the researches have mainly focused on current mode circuits. In this framework, operational transconductance amplifier (OTA), double output operational transconductance amplifier (DO-OTA), current conveyor (CCII) and four terminal floating nullor (FTFN) are some of the proposed current mode circuits. Some other current mode circuits have also become popular so in the design of analog circuit structures such as active filters, oscillators, new current mode circuits have been proposed instead of the classic voltage mode circuits [1-5].

The advances in CMOS technology increase the performance of the active circuit structures and wider bandwidth, higher accuracy can be achieved.

In this paper we proposed a high performance CMOS operational amplifier and the performance of the circuit, with the help of the SPICE program, is shown on a high order active filter for video applications.

2 High Performance CMOS Operational Amplifier

Proposed high performance operational amplifier is shown in Fig.1. The circuit is consist of a rail to rail input and output stages [6-9].Cascode in the input stage is wide bandwidth and high speed, self biased complementary folded cascode structure [12].

As the supply voltage decreases, voltage limits at the input of an operational amplifier become narrower. These limits depend on two important factors. First is the supply voltage and second is the character of the input stage. Rail to rail input stages are preferable in today's low voltage operational amplifiers to handle input voltages from rail to rail [6-9].

In this paper we use a rail to rail input stage. To reach the negative supply rail, M1 and M2 PMOS transistors are used. Similarly, to reach the positive supply rail M3 and M4 NMOS transistors are used. The input stage operates according to the principle that NMOS differential pair is active for high input common mode voltages, while for low input common mode voltages PMOS differential pair is active.

The most important drawback of the rail to rail input stage is the varying transconductance (g_m) according to the operating mode. Because NMOS differential pair is on for high input common mode voltage, whereas PMOS differential pair is on for low common mode voltage and there is also a region where both pairs are active. This situation affects the performance of the circuit and causes a major problem.

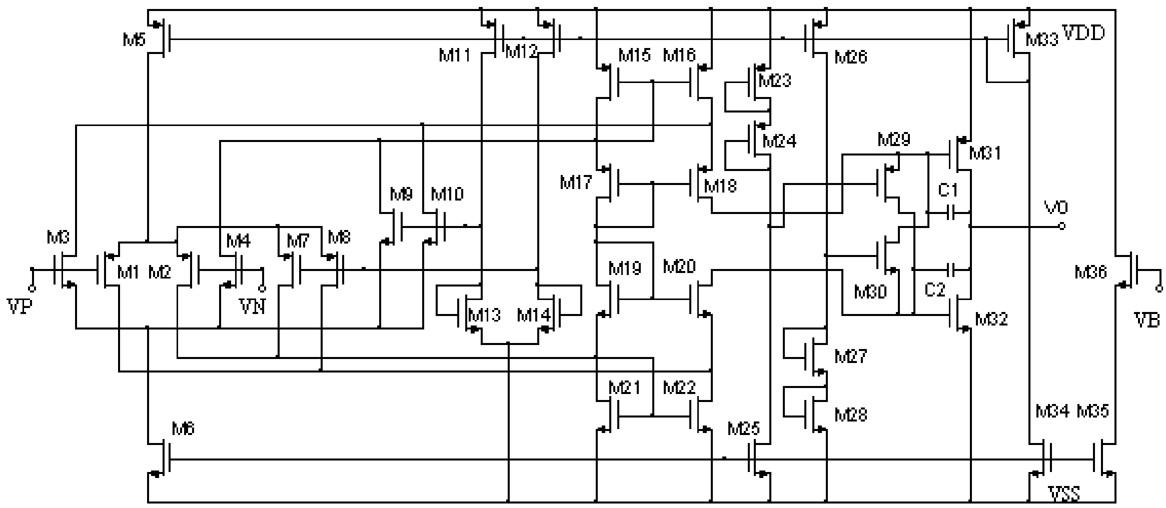

Fig.1 Proposed High Performance CMOS Operational Amplifier.

Unity gain bandwidth of a two stage opamp is described by the formula below [11]

$$f_1 = 2\pi \frac{g_{mt}}{C_c} \quad (1)$$

where g_{mt} is the transconductance of the input stage and C_C is the compensation capacitor. To obtain a sufficient phase margin the second pole in the open loop transfer function must be two and a half times bigger than the unity gain bandwidth. To meet this requirement and the stability condition input stage transconductance should not be affected by the common mode voltage. This problem can be solved by the current switching method.

For high common mode input voltages where NMOS input transistors operates, PMOS input pair is not active so the bias current that is supposed to flow through the PMOS transistors , flows through the tail transistor. Similar case is true for NMOS pair. In the middle of the common mode voltage, when both transistor pairs are active, input transconductance must be half of the transconductance in comparison with one pair is active to obtain a constant transconductance. This is satisfied by the current switches which steal ¾ of the bias current of input transistors. Consequently, the bias current on the input transistors become ¼ of its value when one pair is active and the transconductance is halved. In the case of double switches (M7-M8, and M9-M10), not only transconductance is constant, but also the output current is not affected by common mode input voltage variations which easies the design of summing circuit and also improving the common mode rejection ratio (CMRR) of the amplifier. The current switch transistors in the circuit according to common mode input voltage decide which differential pair is active and take the non-active pair's tail current, divide it into two equal parts and reflect this to the output. In this way the output currents to the summing circuit become constant and since the sum of the output current is constant, transconductance also becomes constant [9].

The output stage of the operational amplifier includes M31 and M32 transistors that can operate from rail to rail. Output stage is biased in class AB. Diode connected M23, M24, M27, M28 transistors supply the bias current [13]. Using these transistors Vab reference voltage is produced which bias the output transistors. M29 and M30 transistors increase the maximum output voltage and let the output stage to drive smaller resistive loads.

3 Simulation Results

The performance of the proposed opamp is shown by SPICE program. The circuit is based on MIETEC 0.5µm CMOS process. Supply voltage is ±2.5V. Dimensions of MOS transistors are shown in Table 1.

Table 1 Dimensions of MOS transistors.

M1,M2=450u
M3,M4=100u
M5,M23,M24,M25,M34,M35=20u
M6,M11,M12,M14,M15,M16, M21,M22,M26,M33=10u
M7,M8,M13=5u
M9,M10=4u
M17,M18,M19,M20=50u
M27,M28=3.5u
M29,M30=40u
M31,M32=400u
M36=25u
Length of all transistors are 0.5u

SPICE simulation results are shown in Fig.2, Fig.3, Fig.4, and Fig.5. It can be noticed that the circuit has a large output voltage range, large bandwidth even in compensated case, good step response and almost constant input stage transconductance. Main simulation performance parameters are shown in Table 2.

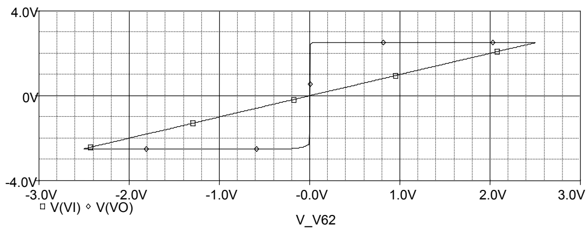

Fig.2 DC Characteristic of the opamp.

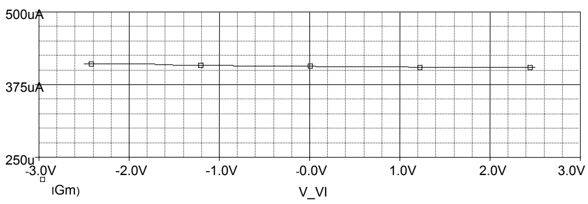

Fig.3 Change of input stage transconductance.

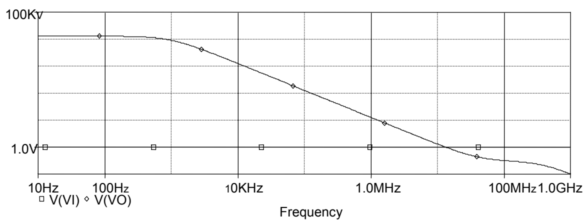

Fig.4 AC Characteristic of the opamp.

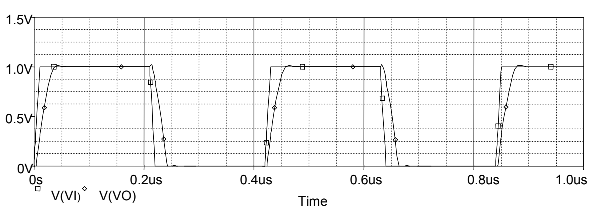

Fig.5 The large signal step response of the opamp

Table 2 Simulation results of the proposed operational amplifier.

Load	R=1Meg, C=1p
Supply Voltage	+2.5V -2.5V
Compensation Capacitor	2pF
Unity gain bandwidth	13MHz
Phase margin	70°
Open loop gain	82dB
Input voltage range	-2.1V, 1.5V
Output voltage range	-2.5V, 2.5V
Input offset voltage	5mV
Power dissipation	20mW
Slew rate	26V/µs
Settling time (%1)	50ns
CMRR@1MHz	82dB
Input noise voltage@1kHz	9nV√Hz

4 The opamp in high order active filter for video applications

The performance of the opamp is shown by using it in an active filter circuit. The circuit is opamp based classical active filter [10]. The circuit is shown in Fig.6. The filter is consist of two notch filters and a low pass filter. The transfer function of the filter is described by the formula below.

$$H_{BP}(s)=\frac{H_1(s^2+\omega_{Z1}^2)}{s^2+\frac{\omega_{P1}}{Q_{P1}}s+\omega_{P1}^2}\frac{H_2(s^2+\omega_{Z2}^2)}{s^2+\frac{\omega_{P2}}{Q_{P2}}s+\omega_{P2}^2}\frac{H_3\omega_{P3}^2}{s^2+\frac{\omega_{P3}}{Q_{P3}}s+\omega_{P3}^2} \quad (2)$$

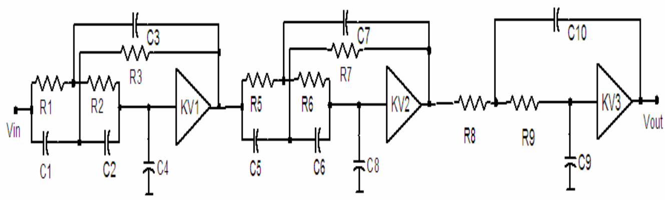

Fig.6 Opamp based sixth order elliptical low pass filter.

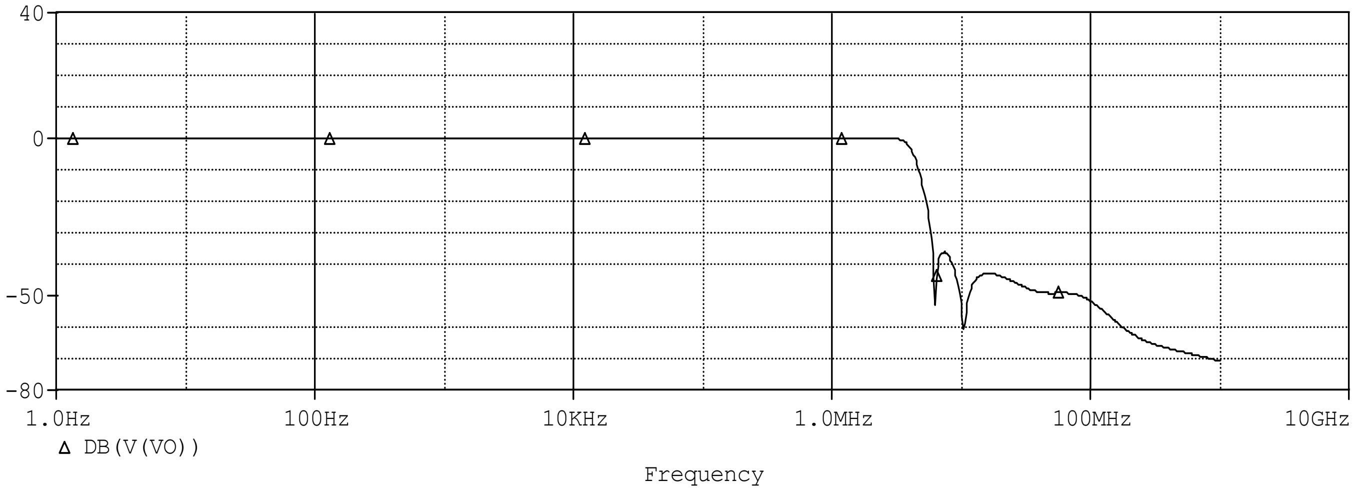

Fig.7 The frequency response of the opamp based sixth order elliptical low pass filter.

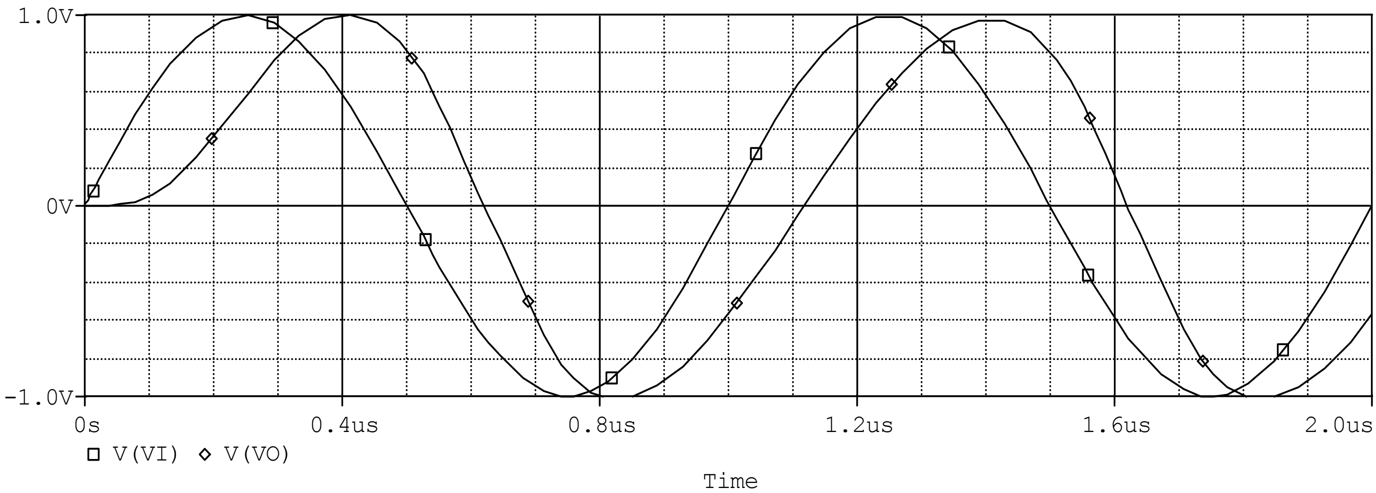

Fig.8 Large signal response of the sixth order opamp based low pass filter.

Filter circuit is designed to pass the signals up to 4.5 MHz and suppress the signals over that value sharply. In the filter, $C_1 = C_2 = 1.25$pF, $C_3 = 2.5$pF, $C_4 = 0.1$ pF, $C_5 = C_6 = 0.75$pF, $C_7 = 1.5$pf, $C_8 = 0.5$pF, $C_9 = C_{10} = 1$pF, $R_1 = R_2 = R_5 = R_6 = R_8 = R_9 = 20$kOhm, $R_3 = R_7 = 10$kOhm are used. It is seen that the capacitors can be easily integrated. Proposed opamp is used in the filter circuit as the amplifiers. The gain of these amplifiers are $K_{V1} = 3.97$, $K_{V2} = 4.33$, $K_{V3} = 1.275$ Resulting frequency response is shown in Fig.7. In order to show the large signal response of the circuit, we use a 1 MHz ,1V signal and the results are shown in Fig.8. As it seen from the Figure 7 and 8, using the proposed opamp, the filter circuit which can only operate in kHz range using classical operational amplifiers can now operate in MHz range and can be used for video applications. The input large signal at 1MHz frequency, 1V amplitude can successfully be processed by the filter and distortion response for that signal is quite good which can be seen from Fig.9. These results can not be achieved by using classical operational amplifiers.

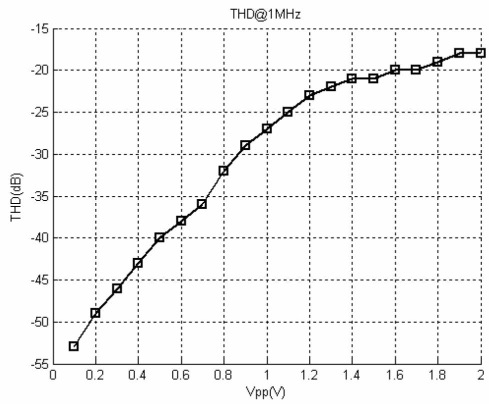

Fig.9 Distortion of the sixth order opamp based low pass filter (Vpp is the peak to peak voltage).

5 Conclusion

In this paper, a high performance operational amplifier is proposed. The performance of the opamp is shown by SPICE program and the opamp is used in an opamp based classical active filter topology. The opamp have a rail to rail input stage and a rail to rail output stage. Proposed operational amplifier gives new possibilities to circuit designers in using classical opamp based circuit structures in higher frequencies.

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