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IMPROVED GAIN TWO STAGE CLASS-A/AB OP-AMP WITH SYMMETRICAL SLEW RATE

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***Abstract*— This paper presents a simple technique to achieve the high gain band width product (GB) and symmetrical slew rate, by employing the different types of two-stage class A/AB Op-amp architectures. It is a combination of cascode Op-amp at input stage and class A/AB amplifiers at the output stage. Different types of op-amps are implemented and simulated in mentor graphics tool at 130nm technology. Simulation results show a 53.49% improvement in gain and 10 to 14 times improvement in GB besides achieving the symmetrical slew rate.**

***Index Terms*— Cascode op-amp, Class AB Op-amp, Gain band width product, Symmetrical slew rate.**

I. Introduction

Two stage or Miller Op-amps are general choice for low voltage applications for capacitive/resistive loads that require rail-to-rail output swing. Conventional two stage class-A Miller Op-amp is shown in figure 1. It is defined by moderate gain, asymmetrical slew rate with high positive slew rate and low negative slew rate. It is given by $SR-=2I_B/C_L$[1]-[4]. where I_B is bias current. Cascode amplifier is used as second stage. Low negative slew rate is due to the output Q7 transistor acts as a constant current source with value twice of bias current. Slew rate can be increased by increasing the value of I_B. It requires very small additional hardware circuitry. Class AB amplifier is used to improve the negative slew rate and in order to maintain low static power dissipation and with capability to generate output current that are essentially larger than the output stage quiescent current. This arrangement improves the current efficiency, defined as the ratio of the maximum output current to total op-amp static current (including current replicating branch at second stage is added to achieve class AB operation), i.e., $CE=I_{outmax}/I_{Qtotal}$.

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The output stage operates as a push-pull amplifier and provides dynamic class-AB operation with symmetrical slew rate and large positive and negative output currents.

Adaptive loads and different types of cascode amplifiers are used at both input and output stages to improve the gain and gain bandwidth product by providing the high output impedance. In this brief, two stage class A/AB Op-amps with high gain and mostly symmetric slew rate are presented. The proposed topologies are described in section.2

II. Proposed Two-Stage Op-amps

A. Two-stage class A Op-Amps with Cascode amplifiers

Cascode amplifier is the cascade connection of common source and common gate amplifiers. This connection improves not only the gain of the device but also enhances the gain band width product.

N-type, P-type and combination of N-type and P-type cascode amplifiers are used in two stage Op-amps. These structures improve the gain of the Op-amps greatly. V_{bsat}, V_{bn} and V_{bp} biasing voltages are given to Q8, Q9, Qn9 and Qp8 transistors which forces them to operate in the saturation region in fig.2, fig.3 and fig.4 respectively. V_b is the required voltages to operate saturation regions for Q3 and Q7 which acts like a constant current sources with value of $2I_B$. Q3 provides the proper biasing current to the first stage of the Op amp and Q7 achieves operations of the class A amplifier (Q6(CS amp) and Q7(CB amp))[5]. Class A amplifier improves the output resistance. Due to this, the gain of the device improves and negative slew rate decreses. To improve the negative slew rate and achieve the symmetrical slew rate without degrading the gain band width product, two stage class AB op amps architectures are proposed.

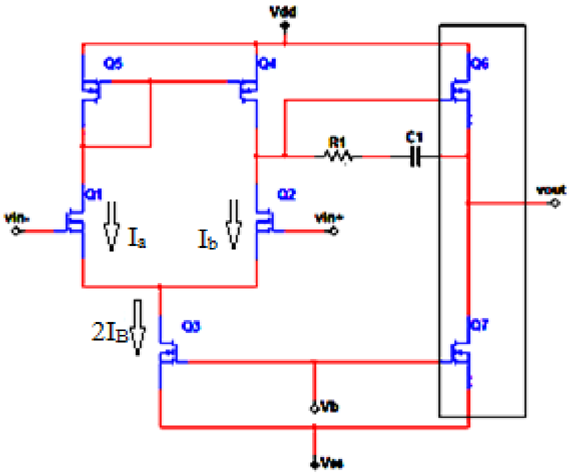

Fig.1. A conventional two stage miller class A Op-amp.

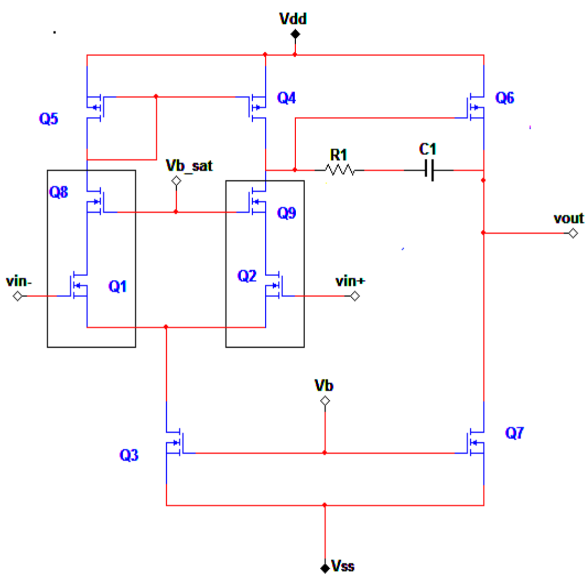

Fig.2. Two stage class A Op-amp with cascode amplifier at input stage

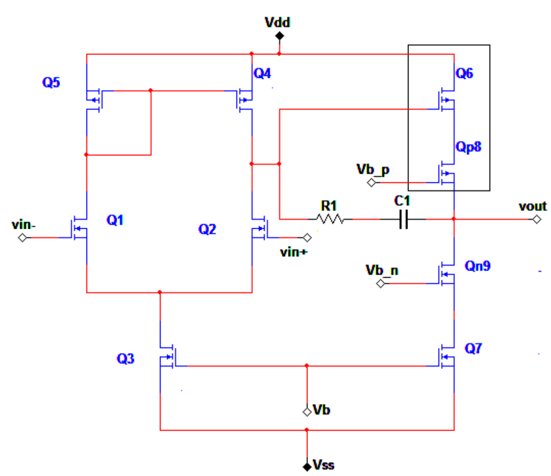

Fig.3. Two stage class A Op-amp with PMOS cascode amplifier at output stage

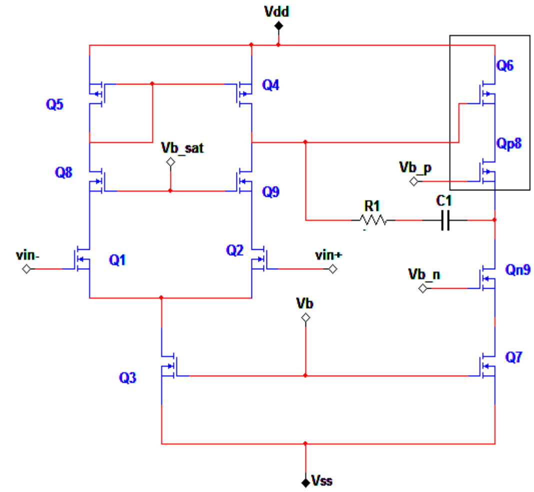

Fig.4.Two stage class A Op-amp with cascode amplifier in both input and output stages

B. Two stage Class-AB Op-Amps using current replicating branch with Adaptive loads and cascode amplifiers

Class AB amplifier operation is achieved by the current replicating branch(Q10 followed by Q11) at the output stage. Two different alternatives loads at input stages are represented in Fig. 6 and 7, which are named as adaptive load type I and II, respectively. Both the type I and II loads exhibits large variation of output resistance of transistors Q12-Q13 which are operated in between triode and saturation regions [1]. Bias voltage V_{bR} sets these transistors at the boundary of the triode and saturation regions in quiescent conditions. These two cases lead to increase in currents, I_a or I_b, which causes transistors Q12 or Q13 to go into triode mode. This leads to develop in large Drain-Source voltages. Eventually these changes cause large variations at nodes a and b, which lead to large currents in the output transistors Q6 and Q7. The operation of outstage is similar to that of a push pull amplifier. For large positive currents Q6 is ON state and Q7 is OFF state respectively and for negative currents vise versa. Now the entire circuit acts like two stage class AB op amp, that achieves a symmetrical slew rate.

To improve the negative slew rate, adaptive load is included in the current replicating branch at the output stage as shown in fig. 8. In this circuit, the bias voltage with value $V_{btriode} = V_{SS}+V_{GS}+V_{DSsat} = V_{TH} + 2V_{DSsat}$ is required at the gate of Q12, where $V_{DSsat}=V_{GS} - V_{TH}$ is the minimum V_{DS} voltage to operate in saturation [1]. This $V_{btriode}$ leaves a quiescent drain-source voltage for Q12 with value V_{DSsat}, which causes Q11 to operate (under static conditions) at the boundary between the triode and saturation regions which leads to extremely large negative output currents thereby giving high negative slew rate, which is approximately equal to the positive slew rate.

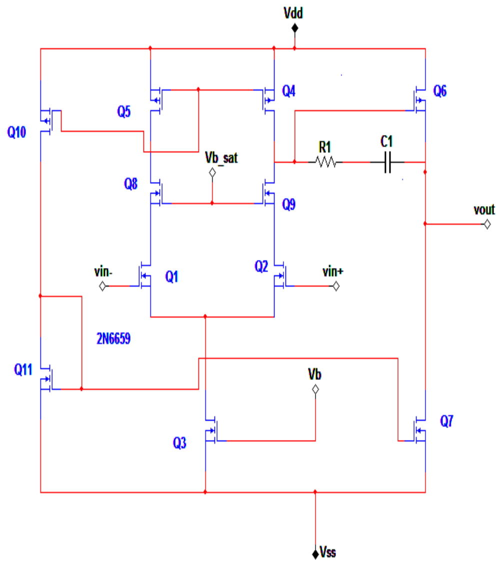

Fig.5. Two stage Class-AB cascode op-amp with current replication branch.

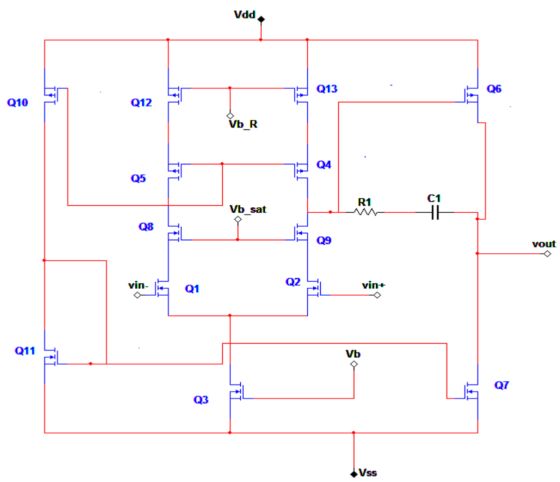

Fig.6. Two stage Class-AB cascode op-amp with current replicating branch using adaptive load I

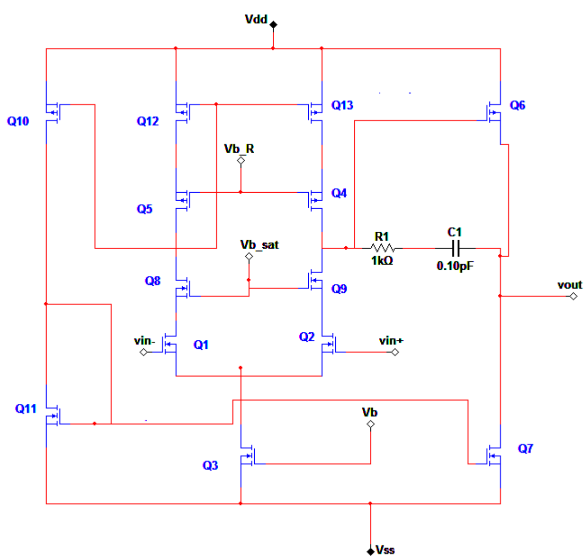

Fig..7. Two stage Class-AB cascode op-amp with current replicating branch using adaptive load II.

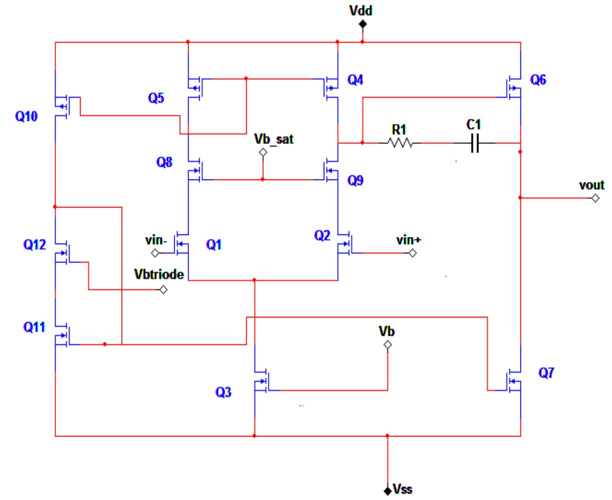

Fig.8. Two stage Class AB cascode op-amp with current replicating branch using adaptive load.

III. Simulation Results

Transient, DC and AC analysis simulations have been made with different Op-amps and results are shown in Fig.9 to 16 and table II. The comparisons are made between slew rate, output currents, gain, gain bandwidth product, phase and different parameters of the different Op-amps which are mentioned in this sections and simulation results are shown in the Table.II. The device dimensions are mentioned below Table.1.

TABLE. I
DEVICE DIMENSIONS

Transistors	Aspect ratio
Q1,Q2	50/1
Q3	100/1
Q4,Q5	140/1
Q6	280/1
Q7	100/1
Q8,Q9	50/1
Q10	28/1
Q11,Q12	10/1

I_b=100uA,C_L=30pF,V_{DD}=1.65V,V_{SS}=-1.65V,R_1=2Kohm and C_1=10pF are used in the proposed circuits.

Fig. 9 to 16 shows the simulated transient pulse response of the two stage op-amp circuits working as voltage followers with unity gain. A pulse of range from -200 to 600 mV and a frequency of 200 kHz is applied as input signal so that the pulse width is 2.5µs. The response of the two-stage op-amps is replica to the input pulse, but there is problem with negative slew rate in the Fig.1 to Fig. 4 circuits. This drawback is overcome by means of using adaptive loads and current replicating branches which are shown in the Fig.5 to 8 and respective transient response is shown in the Fig. 13 to Fig. 16.

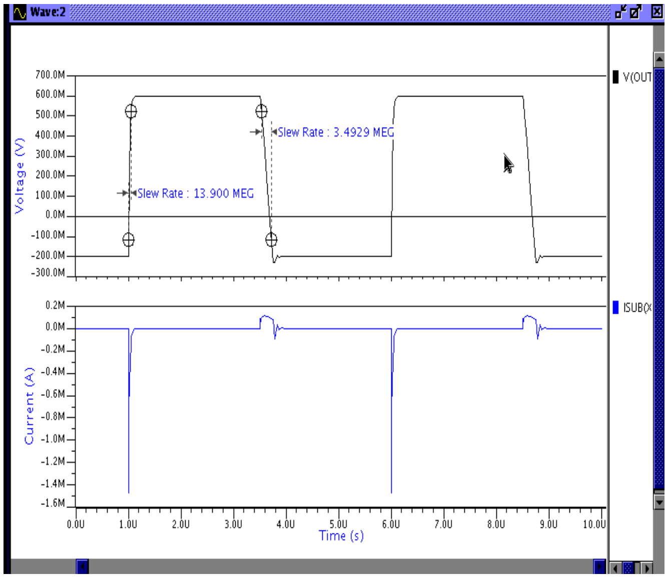

Fig. 9 . Transient response for conventional two stage miller class A Op-amp.

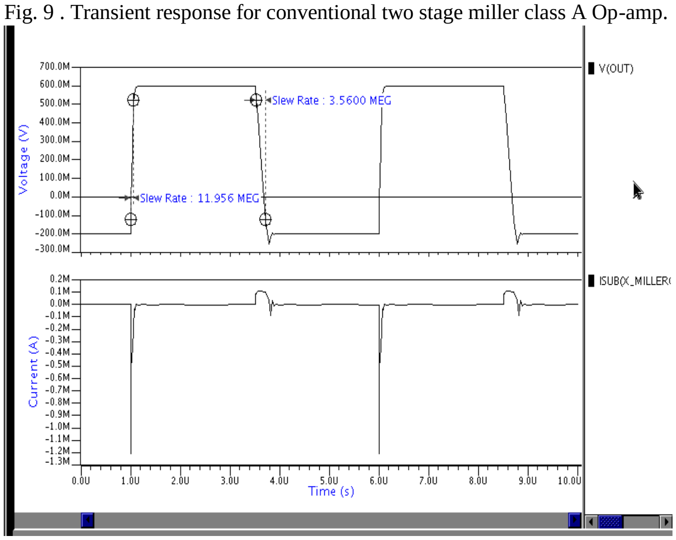

Fig. 10. Transient response for Two stage class A Op-amp with cascode amplifier at input stage.

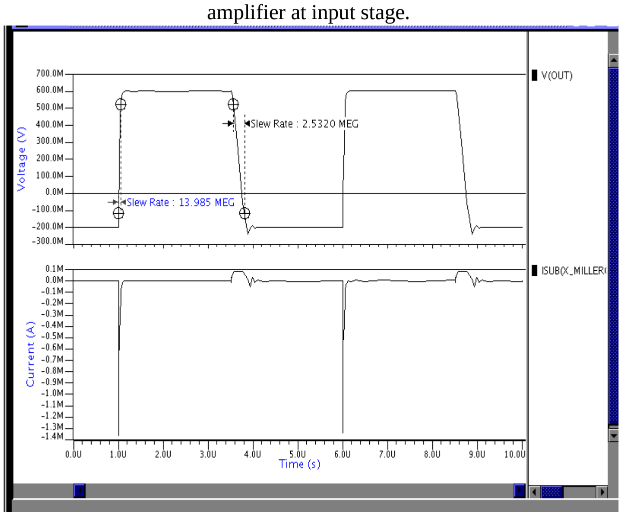

Fig.11. Transient response for Two stage class A Op-amp with PMOS cascode amplifier at output stage

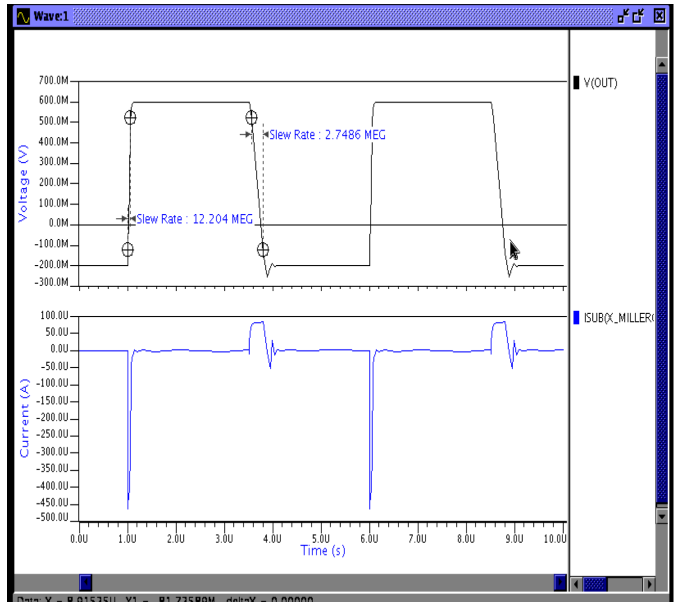

Fig.12. Transient response for Two stage class A Op-amp with cascode amplifier in both input and output stages

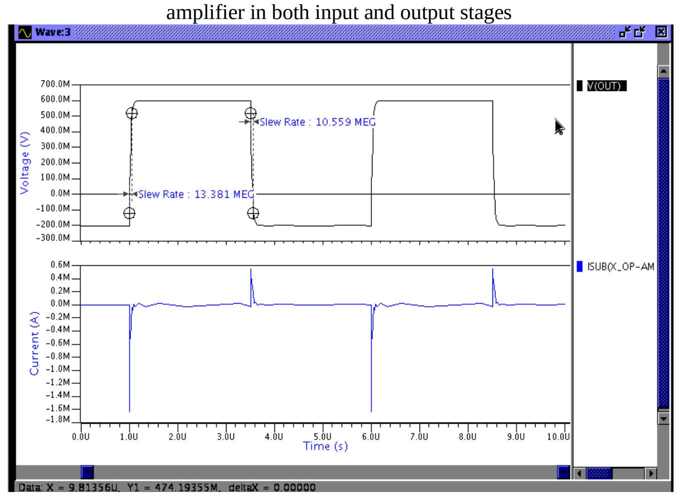

Fig.13. Transient response for Two stage Class-AB cascode op-amp with current replication branch.

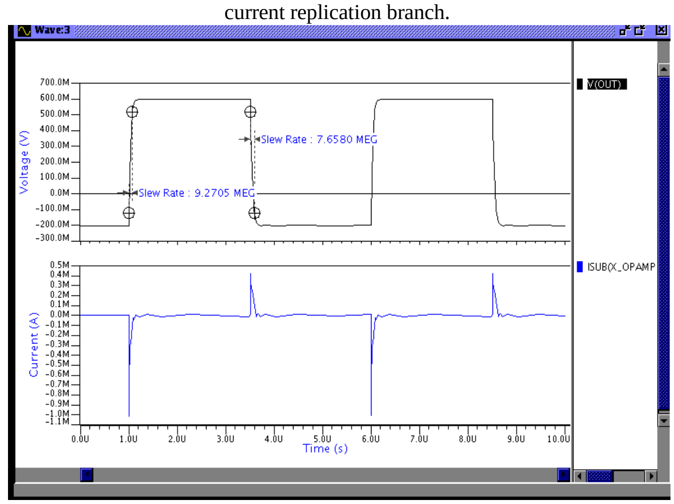

Fig. 14. Transient response for two stage Class-AB cascode op-amp with current replicating branch using adaptive load I

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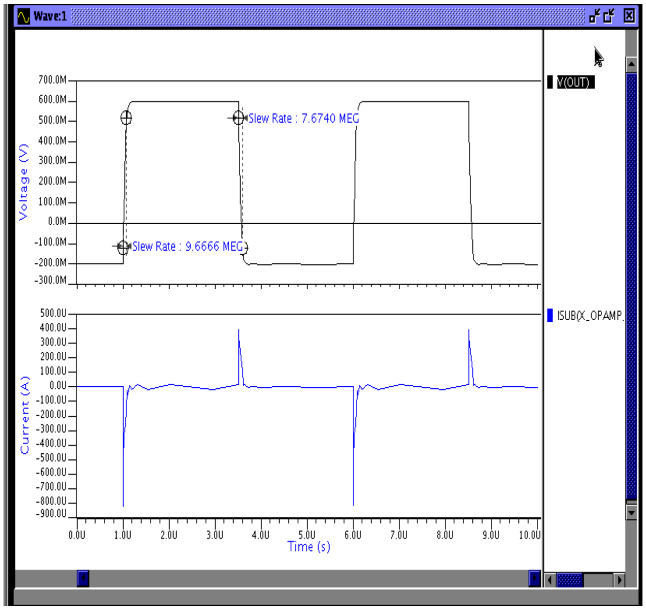

Fig.15. Transient response for two stage Class-AB cascode op-amp with current replicating branch using adaptive load II

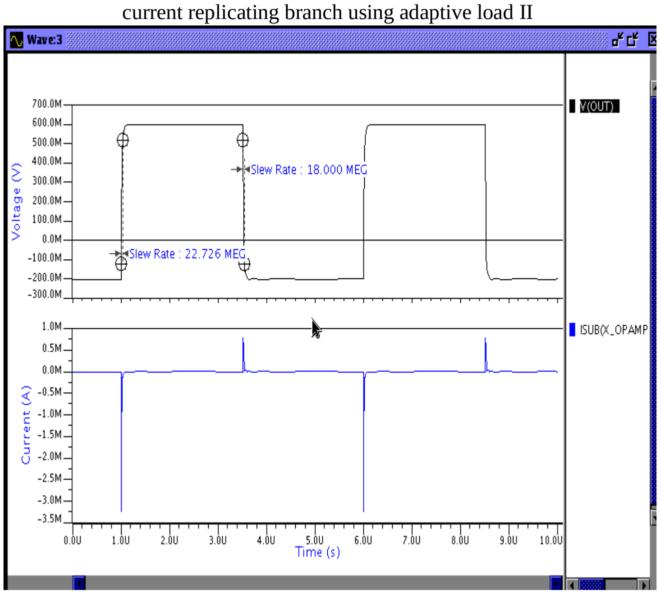

Fig.16. Transient response for Class AB two stage cascode op-amp with current replicating branch using adaptive load

Table II summarizes the simulation results of the above circuits. It is observed that the negative slew rate of the proposed circuits, are about four to five times larger than the conventional op-amp. Consequently, almost symmetrical performance is achieved, especially with the topology with adaptive load with current replicating branches, which has about 22.74 V/µs positive slew rate and 18.0 V/µs negative slew rate. But due to the current replicating branch at the output stage of the Op amp, power consumption is increased.

Finally it is observed that the gain of the two-stage op-amp improves by53.49% and gain bandwidth product increases by 10 to 14 times when compared to conventional two-stage-amp. As a result, common mode rejection ratio as well as power supply rejection ratio is improved.

TABLE. II
FEATURE COMPARISONS OF THE PROPOSED ARCHITECTURES

Parameter	Fig.1	Fig.2	Fig.3	Fig.4	Fig.5	Fig.6	Fig.7	Fig.8
Power(mv)	0.916	0.88	0.789	0.755	0.751	1.1466	1.57	2.38
SR-(V/us)	3.492	3.560	2.5319	2.786	7.66	7.875	10.559	18.00
SR+(V/us)	13.9	11.956	13.163	12.204	9.268	9.67	13.381	22.744
Offset(mv)	0.329	0.216	579.03	-0.718	-1.2721	-1.27	-1.277	-1.2866
A_0(dB)	56.34	61.606	86.488	65.98	60.837	60.66	60.67	60.074
BW(KHz)	1.52	9.133	0.5586	7.23	13.606	10	9.378	14.414
GB(MHz)	1.0	10.987	11.79	14.407	14.9	10.796	10.131	14.53
PM(^{0})	88.624	87.321	74.893	83..0714	101.798	98.813	102.3	104.325
CMRR(dB)	70.02	87.859	81.4299	92.183	115.924	116.105	96.056	95.4817
PSRR+(dB)	59.41	68.946	86.223	65.88	111.367	109.85	109.86	104.94
PSRR-(dB)	54.8986	60.882	89.648	51.31	60.17	59.27	59.74	58.074
CMIR	-1.65 to 1.59	-1.64 to 1.2	-1.64 to 1.65	-1.65 to 0.6	-1.62 to 0.2	-1.64 to 1.2	-1.65 to 1.4	-1.65 to 1.4

IV. Conclusion

This paper focuses mainly on symmetrical slew rate and gain band width product. By using current replication branch and adaptive loads slew rate is achieved and by adapting Cascode amplifier at input and output stage of op-amps, an improved gain band width product is achieved.

Instead of cascode amplifier at input and output stage of two-stage op-amps, folded cascode amplifiers are to be tested for improvement in the gain and slew rate.

V. Acknowledgment

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