

Design and Analysis of High Bandwidth RGC Transimpedance Amplifier using Differential Tunable Active Inductor

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Abstract— This paper presents high bandwidth TIA which uses regulated cascode (RGC) technique along with differential tunable active inductor to increase the bandwidth. Proposed circuit uses RGC input topology to lower the input impedance and isolates input parasitic capacitances of the circuit. Active inductor is used to give inductive peaking effect to improve the bandwidth of the circuit. Differential tunable active inductor is used to provide tunable bandwidth of the circuit by varying the control bias voltage V_{ctrl} . Simulation results for 0.18 μ m CMOS technology, 1.8 V supply voltage shows 3-dB bandwidth to be 6.12 GHz at V_{ctrl} 0.1 V along with 35.65 dB gain. Bandwidth is observed to be 3-3.5 times higher as compared to the previous works of TIA.

Index Terms— Differential tunable active inductor, TIA, Bandwidth enhancement.

I. INTRODUCTION

Lot of research has been published on the design of various optical communication receiver systems. smaller small signal input impedance is observed because of the RGC configuration [11]. Bandwidth enhancement using active inductor were shown in paper [7]. This section is mainly focused on the wideband transimpedance amplifier (TIA). Just after the photodiode, TIA circuit is placed that converts photodiode current to a voltage level for the next stage. Because of the high parasitic capacitances of the photodiode, a large time constant is observed at the input node that reduces the bandwidth of the circuit as low-frequency pole is created when TIA have high input impedance. TIA is widely used in optical communication receivers and RF applications [12]. Previously designed TIA's were made of Si-bipolar technology which are bulky in size. To overcome this issue CMOS technology has been adopted which provides a high level of integration and reduces area on chip. TIA circuit determines the parameters such as speed and sensitivity. Inductor is one of the most important transimpedance amplifier (TIA) element for high frequency application and RF systems. Spiral inductor increases chip size and also increases its cost, thus it is necessary to reduce the area of inductor used in TIA. Using differential tunable active inductor, the area problem can be solved. TIA employs a negative feedback to create a low impedance, furthermore RGC topology is used in the TIA to reduce the proposed circuit's input

impedance. The large feedback in the proposed schematic provides increased 3-dB bandwidth. In this proposed circuit bandwidth of the TIA has been improved. In section II there is a brief description of differential tunable active inductor, its operating ranges and its inductance values at different control voltages V_{ctrl} calculated in the linear region of its operation. Proposed TIA circuit using active inductor is shown in section III. Simulation results were shown in section IV along with the comparison table3. Conclusion is given in section V.

II. DIFFERENTIAL TUNABLE ACTIVE INDUCTOR

Lu et al proposed the active inductor shown in figure1 and its equivalent is shown in figure 2. The active inductor shown is differentially configured gyrator-C. M_5 and M_6 transistors behaves as voltage controlled resistors as they are biased in the triode region and behaves as voltage controlled resistors and is controlled by bias voltage V_{ctrl} . Rest all other transistors are biased in the saturation region. Negative feedback is there in the active inductor and is as follows: when we increase V_2 and decrease V_3 then it has been observed that gate voltage V_{g2} increases and gate voltage of V_{g1} decreases because M_3, M_4 have common gate operation. M_1, M_2 source followers make sure that V_2 and V_3 reduces by the same amount approximately. RLC equivalent circuit of the differential tunable active inductor is shown in the figure1. Let us take gds_5 and gds_6 as the channel conductances of M_5 and M_6 . Active inductor small signal equivalent circuit [9] shows inductor differential input impedance as:

$$Z = \frac{2[s(Cgs_1 + Cgs_3) - gm_3 + gds_5]}{gds_5[gm_1 + gm_3 + s(cgs_3 + cgs_1)]} \quad (1)$$

RLC parameters of active inductor can be given as [9]:

$$R_2 = \frac{2}{gds_5} \quad (2)$$

$$R_1 = \frac{2(gds_5 - gm_3)}{gds_5(2gm_3 + gm_1 - gds_5)} \quad (3)$$

$$L = \frac{2(Cgs_1 + Cgs_3)}{gds_5(2gm_3 + gm_1 - gds_5)} \quad (4)$$

The condition required for R_1 and L to have the positive values is: $2gm_3 + gm_1 > gds_5$ and $gds_5 > gds_3$. The active inductor inductance can be tuned by varying control bias voltage V_{ctrl} and subsequently gds_5 . An increase in control voltage V_{ctrl} will take M_5 and M_6 to saturation region from triode region thus reduces gds_5 and gds_6 . This will result in increase of the inductance.

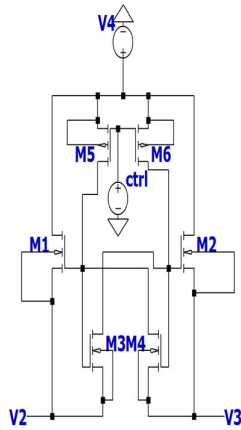


Figure 1. Differential tunable active inductor

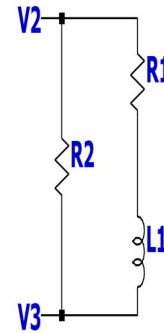


Figure 2. Equivalent schematic of differential tunable active inductor

By using the relation :

$$Z = j\omega L \quad (5)$$

Inductance values and maximum operating range of the differential tunable active inductor is being calculated at different control voltage V_{ctrl} and at different frequencies as shown in section IV (see table 2). Active inductor can only be used in the linear region of its impedance curve graph.

III. PROPOSED CIRCUIT DESIGN OF TIA

Figure 3 shows the conventional circuit of TIA, it has very large input parasitic capacitances because it includes PD capacitance, protection diode capacitance, electrostatic discharge and RGC circuit have its own input parasitic capacitances as well. Because of these capacitances 3-dB bandwidth is deteriorated. Figure 4 shows the proposed circuit design of the RGC TIA. The proposed circuit consists of positive amplifier that have M_4 , R_3 , M_1 and active inductor that has been put into a conventional RGC circuit. To the input node, feedback signal is returned by M_1 and therefore making it more virtual ground and hence the circuit behaves as a current buffer, that makes the input resistance smaller than before and also circuit becomes more stable.

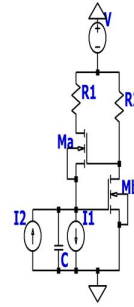


Figure 3. Conventional RGC TIA

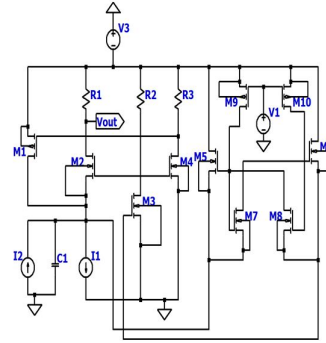


Figure 4. Proposed RGC TIA with differential tunable active inductor

The bandwidth is improved because of the addition of the active inductor as the large gate capacitance of M_3 is isolated at higher frequencies. (W/L) dimension of M_3 is required to be high to hold the bias of the local feedback loop and hence miller capacitance is large. Therefore active inductor reduces the input impedance and hence there is more improvement in the bandwidth. Because of the use of the active inductor rather than passive one and MOSFETs in the design, area is saved. Due to small voltage head-room of the components used in the proposed RGC TIA, stability and linearity is improved as well..

IV. RESULTS

The performance of the proposed TIA circuit is verified using 0.18 μm CMOS technology at 1.8 V power supply. From the impedance graph of the active inductor shown in figure 5, Operating range is maximum at control voltage V_{ctrl} 0.1 V and is 6.3 GHz, along with inductance value 4.25 nH in the linear region of its operation. Inductance values ranges from 4.78 nH to 23.9 nH at different control voltage V_{ctrl} .. Table 2 shows active inductor's maximum operating range and inductance values at different control voltage V_{ctrl} and at different frequencies. TIA results are written in the comparison table 3 at control voltage V_{ctrl} 0.1 V.

TABLE I. ASPECT RATIO AND OTHER PARAMETERS OF TIA

Transistors	Size($\mu\text{m}/\mu\text{m}$)
M_1	8/0.18
M_2	32/0.18
M_3	20/0.18
M_4	4/0.18
M_5, M_6	112.5/0.18
M_7, M_8, M_9, M_{10}	25/0.18
R_1	650
R_2	440
R_3	499

TABLE II. MAXIMUM OPERATING RANGE AND INDUCTANCE VALUES OF ACTIVE INDUCTOR

Control Voltage ctrl V	Frequency values GHz	Inductance values nH	Inductor max operating range GHz
0.1	2.51	8.22	6.3
	3.98	5.75	
	6.12	4.25	
0.5	2.51	9.05	5
	3.98	6.63	
	5.01	5.54	
1	1.99	15	3.98
	2.51	13.34	
	3.98	7.51	
1.2	1.25	32.35	2.5
	1.99	23.9	
	2.51	19.25	

Figure 6 shows the proposed circuit's simulated frequency response. From the figure 6 we find that the 3-dB frequency bandwidth is 6.12 GHz and the proposed circuit transimpedance gain is 35.65 dB. Input impedance of proposed TIA is observed to be 80.49 Ω at control voltage V_{ctrl} 0.1V as shown in figure 7 and it slightly increases as control voltage V_{ctrl} of active inductor increases. Table 3 shows the comparison of the proposed work with other TIA works. Bandwidth is improved to 6.12 GHz that is approximately 3-3.5 times the bandwidth of the other TIA works.

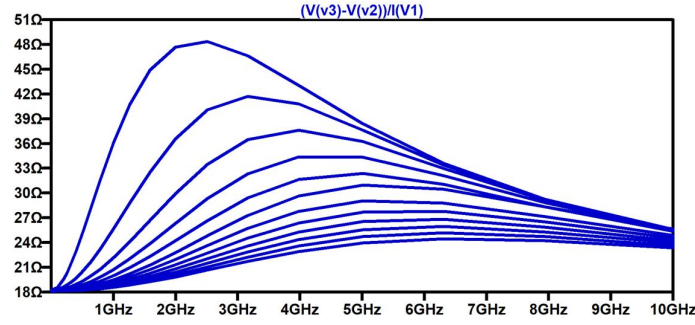


Figure 5. Impedance curves of differential tunable active inductor

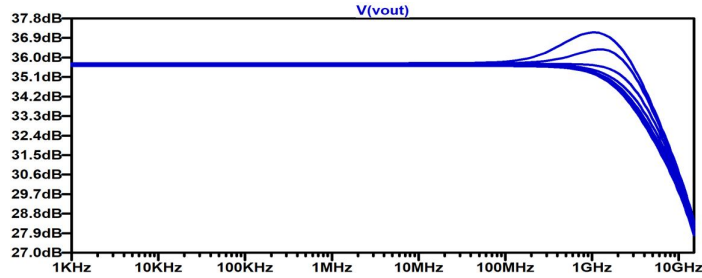


Figure 6. Simulated result of proposed TIA

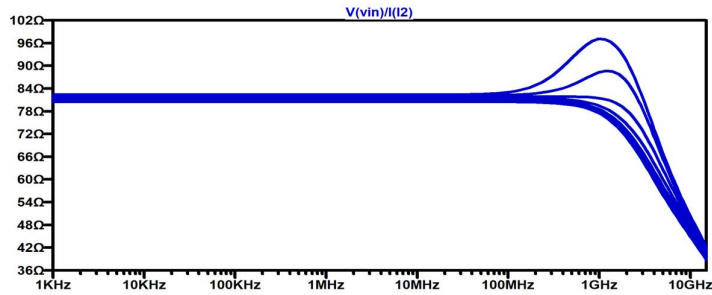
Figure 7. Input impedances of TIA at different control voltage V_{ctrl}

TABLE III. COMPARISON TABLE OF THE PROPOSED TIA WITH OTHER TIA WORKS

reference	[1]	[2]	[3]	[4]	[5]	[6]	Proposed TIA at 0.1 V _{ctrl}
Technology	0.18um CMOS	0.13um CMOS	0.18um CMOS	0.13um CMOS	0.18um CMOS	0.18um CMOS	0.18um CMOS
Bandwidth GHz	1.6 Ghz	1.98	2	0.0025	1	1.2	6.12
Transimpedance gain dB	42.24	76.8	61.5	98	55.5	61.07	35.65
Supply voltage V	1.5	1.8	1.5	1.8	1.8	1.8	1.8
No of active inductors	1	1	1	1	0	1	1

V. CONCLUSIONS

The bandwidth of the proposed CMOS RGC TIA with differential tunable active inductor is improved to 6.12 GHz at control voltage V_{ctrl} 0.1 V and can be adjusted with the tuning of the active inductor via V_{ctrl} . All results are verified at 0.18 um CMOS technology and at 1.8 V power supply. The proposed circuit uses positive amplifier that employs negative feedback and by using active inductor, transistor capacitances isolates that improves the bandwidth of the design. Gain can be enhanced using some gain enhancement techniques like common gate stage, automatic gain control, cascode stages and many more.

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