Design of2 GHz Integrator using Feedforward-Regulated Cascode Operational Transconductance Amplifier

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Abstract: *This paper demonstrates a design of 2 GHz integrator circuit using a feed forward-regulated cascode OTA. The design of integrator circuit using OP-AMP seldom works up to Mega-Hertz range. Operational Transconductance Amplifier, having an advantage of tuning the transconductance using external current source, finds huge amount of applications in the field of analog design. However there are very few OTAs that breaks the Giga-Hertz range, feed forward-regulated cascode OTA being one. This work utilizes the 10GHz bandwidth of feed-forward OTA, to design an integrator circuit. Not only the range of frequency but this integrator design even has the advantage low power dissipation. The work is mathematically verified and the simulation results also depicts the accuracy of the design. This work is simulated in mentor graphics software and a layout has been designed in the MOSFET level.*

Keywords:*OTA, Integrator, PLL, ADC.*

I. INTRODUCTION

The feed forward-regulated cascode OTA proves to be an excellentdevice, having a bandwidth of 10 GHz with a transconductance of 11ms [1]. There are very few OTAs that has broken the Giga-Hertz range. Various microwave applications are well suited for implementation of high speed OTAs, such as phase shifters and oscillators [1]. A generalized design methodology for OTA based current mode Radio Frequency (RF) communication circuits like Phase Lock Loop (PLL), Adaptive Delta Modulator (ADM) and data compressor has been proposed in [12]. In contrast to OTAs using feedback-regulated cascade topologies [2]-[3], the feed-forward fully differential OTAs can diminish the time delay in the cascode regulation and thereby significantly increase its operating speed [1]. OTA being a current-mode device, has an advantage of very less effect due to scaling of MOSFET. Current-mode devices show advantages over their voltage-mode counterparts including increased bandwidth, higher dynamic range, and better suitability for operation in reduced supply environments, simpler circuitry, and lower power consumption [5]. A current mode Analog to Digital converter with adaptive quantization has been reported in [2]. Various works are being reported in the design of modulator circuits, oscillators, phase shifters and many analog circuits using OTAs [4]-[7]. The high demand of low cost, low volume systems, has put pressure on integrating as many parts as possible in a single chip. Also, the need for long duration of operating with a single low-voltage supply in system demands low-power and low-voltage designs [4]. Keeping all in account this work utilizes the feed forward-regulated cascode OTA for designing an integrator circuit. The organization of this paper is as follows, sec-II gives a brief description of operational transconductance amplifier, and feed forward-regulated cascode OTA. Sec-II describes the design of integrator circuit using OTA. The simulation results and layout design are shown in sec-III, followed by conclusion in sec-IV.

II. OPERATIONAL TRANSCONDUCTANCE AMPLIFIER:

The Operational Transconductance amplifier (OTA) is an amplifier whose differential input voltage produces an output current. Thus it is a voltage controlled current source (VCCS). Fig 1. shows the general block diagram of single output OTA.

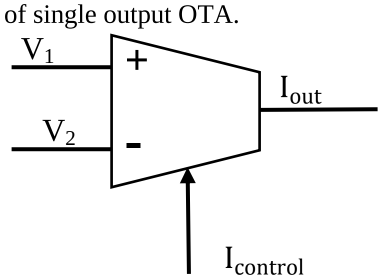

Fig. 1 Basic Block Diagram of OTA

The expression for I out is given by

$I_{out} = gm(V_{in})$ (1)

Where gm is the Trans conductance of the OTA,

$V_{in} = V_1 - V_2$, is the differential input voltage.

$gm = \sqrt{\mu_n C_{ox} \left(\frac{W}{L}\right) I_{control}}$ (2)

$I_{control}$ is the controlling current.

The OTA contains two PMOS regulated cascodes (T1/T2 and T5/T6) and two NMOS regulated cascodes (T3/T4 and T7/T8) where the PMOS cascodes have the same configuration as the NMOS cascodes and their

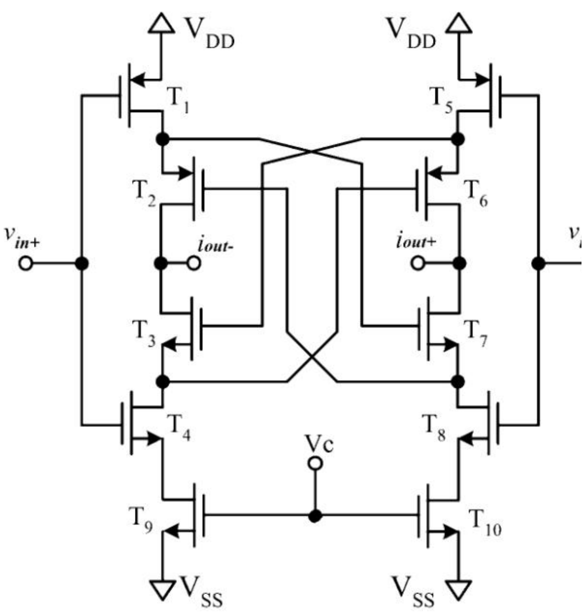

Fig. 2 CMOS Fully Differential OTA Using Negative Feed Forward-Regulated Cascodes. [1]

DC currents are controlled by the two DC current sources at the bottom (T9 and T10) [1]. Instead of local negative feedback, this OTA uses a negative feedforward method for its four regulated-cascodes to speed up the regulating process [1]. In the proposedOTA, the feed forward topology can completely remove the regulating delay and it also eliminates theneed for any DC block and additional biasing circuitry when this OTA is cascaded with copies of itself, which greatly simplifies overall system design [1]. Here for our design purpose we have replaced the transistor T9 and T10 and instead of supplying a controlling voltage we have supplied a controlling current, hence the transconductance will now be proportional to controlling current $I_{control}$.

From eqn (1) and eqn (2) it is clear that I_{out} is a function of differential input and trans conductance , and trans conductance is proportional to the $I_{control}$ which can be tuned, therefore tuning the output current. The other parameters of Transconductance are fixed and modeled by the device designer.The feed forward-regulated cascode OTA in Fig. 2 has differential inputs and differential outputs, which allows the circuit to be used in both positive and negative feedback system configurations [1].

III. DESIGN METHODOLOGY OF INTEGRATOR

The proposed integrator circuit using OTA has been shown in Fig. 3. The overall transfer function of the integrator is

$$\frac{Vout(s)}{Vin(s)} = \frac{1}{1 + s\frac{C}{gm}} \quad (3)$$

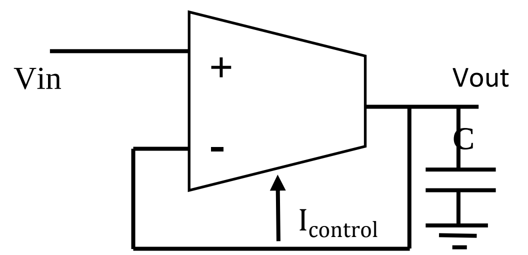

Fig. 3 Integrator Circuit Using OTA.

One of the major advantage of this integrator is the DC problem of the integrator circuit is present. As at zero frequency the gain is unity. Integrator circuit finds a major applications in electronic circuits, and PIDs. One of the major application of integrator circuit is to generate ramp signals. The feed-forward OTA used in this circuit, helps the integrator to generate a ramp signal of 2 GHz frequency. Since the transconductance can be tuned using controlling current, the frequency of the ramp signal can be varied subsequently.

Since an integrator is itself a low pass filter, this circuit can also work as a 1st order LPF with a tunable cutoff frequency.

IV. RESULTS AND LAYOUT DESIGN

Fig. 4 shows the bandwidth of the integrator circuit for$I_{control}$ =10 μA. Since it acts as a LPF, the circuit can be implemented as an LPF of 2 GHz cut-off frequency.

Fig.5 and 6. Shows the simulated time domain response for different periodic signals. For an input cosine wave, the output is a sine wave, i.e. phase shift of 90 degree. Fig. 6 depicts the generation of a triangular wave of 2 GHz, using an integrator.

Fig.7 shows the MOSFET level layout structure of the proposed integrator using feed forward-regulated cascade OTA.

Hence these results validate the operation of the integrator in Giga-hertz range.

DESIGN PARAMETER	
1. VSS	1.5 Volts
2. Length of NMOS	0.8µ
3. Width of NMOS	10µ
4. Zero biased threshold voltage VTH0	'0.1+0'
5. TOX	'2.81E-09'
6. CGDO/ CGSO	'3.85E-10'
7. External capacitor C (µF)	0.001

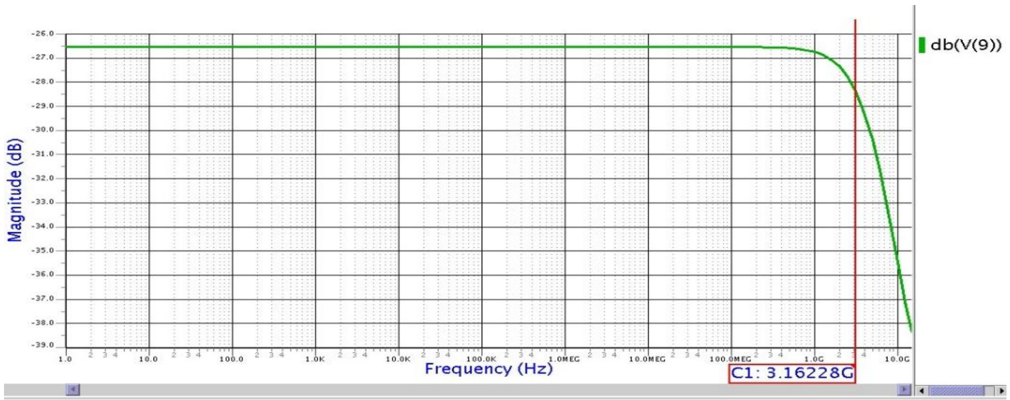

Fig. 4 Frequency Response of the Integrator Circuit, with a Bandwidth of 3 Ghz.

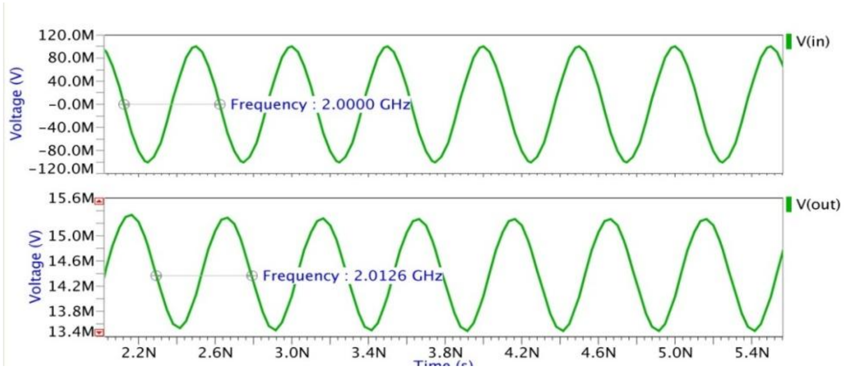

Fig. 5 Integrator Output Response for a Cosine Input of 2 Ghz.

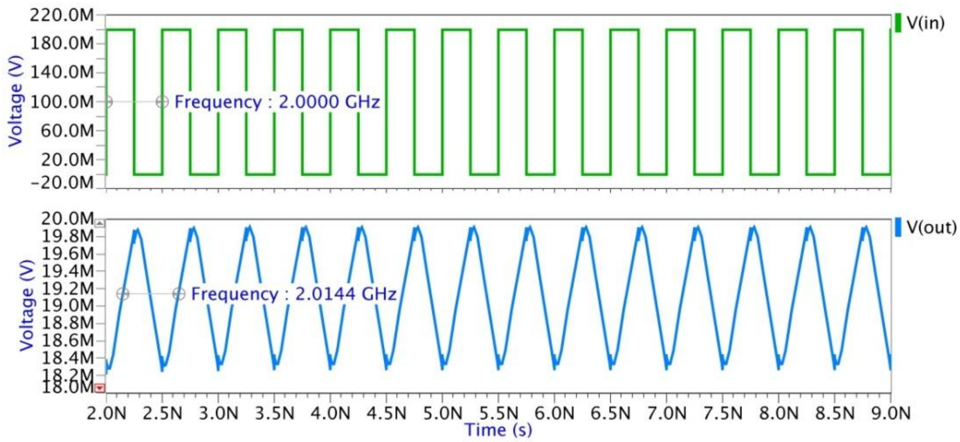

Fig. 6 Generation of A 2 Ghz Triangular Wave Using The Proposed OTA.

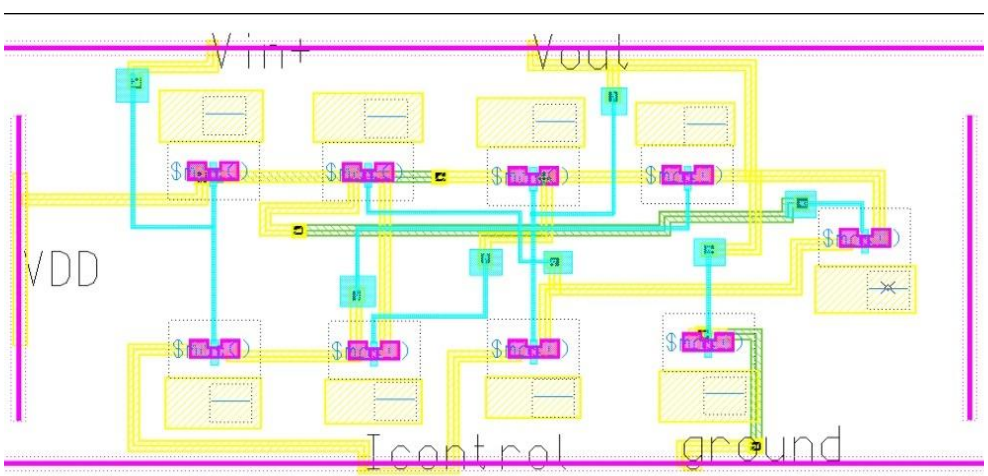

Fig. 7. MOS level Layout Design of The Integrator

V. CONCLUSION

The application of feed forward-regulated cascode OTA has proved to be of immense advantageous in the field of analog and mixed design. The increase in transconductance has improved the bandwidth of the integrator. Integrator being an important block for various mixed designs, this paper gives a new methodology of using an OTA based integrator that can work in giga-hertz range. Further the feed forward cascode OTA can be utilized in realizing various analog circuits for giga hertz range.

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