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Realization of Fractional Order Operations Using CNTFET Based Current Conveyors

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Abstract— In Analog Circuits Low Power and High Performance are main Parameters so it has developed interest in designing carbon nanotube field-effect transistors (CNTFET) for their high mobility nature and lower nano-scale dimensions. CNTFET-based current conveyors are designed using integer order and fractional order oscillator, integrator, and differentiator and simulated in Cadence Virtuoso using a 32 nm CNTFET. FOCC (Fractional order current conveyors) oscillator have better frequency than integer order CNTFET current conveyors oscillators (66 MHz vs. 60 MHz) and they have wider phase zone (45–90° vs. 90°). while integrators and differentiators show better phase, broader bandwidth (100 MHz vs. 80 MHz; 120 MHz vs. 90 MHz). FOCCs also reduces power consumption (50 µW vs. 70 µW for oscillators).

Keywords—Metal Oxide Field Effective Transistor, carbon nanotube field-effect transistors, Fractional order current conveyors, oscillator, integrator and differentiator, Dual output-second-generation current conveyor

I INTRODUCTION

Current conveyors (CC) are fundamental blocks in Analog signal processing, and they are introduced earlier in circuits such as oscillators, integrators, differentiators, and filters. Second-generation current conveyors (CCII) are especially useful owing to their voltage-current properties to provide high performance for amplifiers and filters due to their dual output and input nature. They are mainly specialized by wide bandwidth, high linearity, and low-voltage operation. CNTFET (Carbon Nanotube Field-Effect Transistors) provide more advantages over traditional MOSFET when it comes to CC design. CNTFETs enable improved bandwidth and reduced power consumption through ballistic electron transport. Their potential for scalability to nanometer sizes also provides high integration density. Fractional-order circuits, with components designed from non-integer order calculus, provide increased design flexibility, precision, and control. Such circuits are extensively used in biomedical systems, seismology, battery modelling, and RF design. This paper integrates CNTFET and fractional-order elements to design high-level CC-based applications (oscillators, integrators, differentiators) with bandwidth, speed, power efficiency, and improvements in phase zones.

Carbon Nanotubes (CNT) were found by Iijima (1991) and Bethune (1993) and are tube-shaped nanostructures created through the rolling up of graphene sheets. They exist in the form of Single-Walled (SWCNT) and multi-walled (MWCNT). CNT have remarkable mechanical, electrical, thermal, and chemical characteristics, including tensile strength approximately 100 times that of steel, current density nearly 1000 times that of copper, high thermal conductivity up to 2586 Watt per meter into Kelvin. (MWCNT), good field emission due to high aspect ratio, and semiconducting behavior as a function of chirality (n, m). CNT properties render them interesting for nanoelectronics and resulted in the creation of CNTFET, in which CNTs are employed as channels rather than silicon. CNTFET provide high transconductance (g_m), extremely high carrier mobility (greater than 100,000-centimeter square per Voltage into Second), perfect subthreshold slope, quick current drive, and ballistic or quasi-ballistic transport minimizing scattering losses.

Fractional Order Devices are components obey fractional calculus, with non-integer order derivatives, as opposed to conventional components with integer orders (1, 2). Their impedance/admittance is a function of a fractional power of frequency, contributing to better electrical and mechanical performance.

Fractional Order Elements and their Impedance(Z) is defined as Z is directly proportional to $S^{\alpha}$where (0<α<1) and S is the complex frequency. The types include: Fractional Order Capacitor, with $Z=\frac{1}{Cs^{\alpha}}$ where (0<α<1) acting like a Constant Phase Element (CPE); Fractional Order Inductor, with $Z= Cs^{\alpha}$, acting between a resistor and inductor. Fractor, a general fractional element with $Z=K\ s^{\alpha}$where K is a constant and α can be any non-integer value and applications which include impedance modelling for batteries, supercapacitors, and electrochemical systems; filter design that provides better phase and magnitude response in signal processing; and Analog circuit design that facilitates small, tailored frequency response designs.

The organization of the paper follows in section2 it deals with literature survey in which how CC are developed and DO-CCII are evolved from it and properties of CNTFET associated with current conveyors. Section3 states how DO-CCII structured is designed and usage of different blocks in it.Section4 deals with applications of integer order CNTFET current conveyors like oscillator, differentiator, integrator and Section5 deals with applications of Fractional order CNTFET current conveyors like oscillator, differentiator, integrator so and final section6 Results states the comparison parameters of integer order and Fractional order CNTFET current conveyor for applications of oscillator, differentiator, integrator like bandwidth, frequency and phase zones.

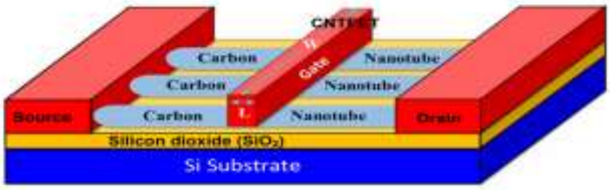

Fig. 1.CARBON nanotube field effect transistor (CNTFET) structure

II LITERATURE SURVEY

A thorough literature survey is conducted and many papers related to CMOS DO-CCII and CNTFET DO-CCII. Some important contributions generally [1] Sedra and Smith (1968), Introduced firstly the concept of the Current Conveyor (CC). CCs are current-mode Analog blocks with unity current gain. And they are Equivalent to OP-AMP in current-mode circuits. Compared to OP-AMP they have High linearity, wide bandwidth, high dynamic range, low power, low noise, and good CMRR. (common-mode rejection ratio). But in general, there are so many types of current conveyors some of them are CCII+(positive output CC), CCII– (negative output CC), ICCC+ (Current Controlled CC), MOCC (Multiple Output CC) but mainly we consider about DO-CCII (dual output current conveyor) as a combination of CCII+ and CCII– in one circuit.[2] Tangsrirat designed BJT-based DO-CCII. Main Uses of it is trans linear elements, complementary current mirrors, and mixed loop which is designed with 19 transistors and ±3 V supply. [3] Gunes et al. designed a CMOS-based DO-CCII at 1.2 μm technology, used 22 transistors and operates at ±10 V and main application is design of a current-mode active filter better than BJT DO-CCII. [4] Centrurelli et al. designed a DO-CCII based on symmetrical OTA which is Implemented in 0.35 μm technology and Supply voltage of ±0.75 V, uses 18 MOS transistors modified DO-CCII structure.[5] Tlelo-Cuautle et al. designed a DO-CCII design using voltage follower and current follower. And implemented in 1.2 μm, with 28 MOS transistors and with±1.5 V supply and it also a modified DO-CCII structure. [6] Abdalla et al. deigned a DO-CCII using 0.35 μm technology and it Uses 24 MOS transistors, operates at ±1.6 V. with very much low power [7] Maghami et al., Proposed a low-power DO-CCII, which is based on a high-gain differential closed-loop structure and implemented at 0.5 μm, operates at ±1.5 V. [8] Yuce et al., Designed an electronically tunable DO-CCII with Technology node- 0.13 μm, supply voltage: ±0.75 V, 22 MOS transistors.[9] Al-Absi et al, CMOS DO-CCII using 0.18 μm technology. Operates at ±5 V, uses 19 MOS transistors which is a main structure used in paper.[10] Mamatov et al.-designed a CNTFET-based voltage differencing current conveyor. With a Technology node-32 nm, very low power consumption (0.3 μW).[11] Chaturvedi et al, designed a current-mode universal filter. Uses Differential Difference Dual-X CCII (DD-DX-CCII) and implemented in 0.18 μm CMOS technology. [12] A. Imran Proposed a CNTFET-based trans linear DO-CCII. Technology node: 32 nm, 19 transistors but its main drawbacks are Low bandwidth (BW) and Low voltage linearity range. [13] Seema et al.-Designed and simulated both CMOS and CNTFET based CCII+. This serves as the foundation for the new CNTFET-DO-CCII in the current work. In this paper, a novel CNTFET based class-AB dual output current conveyor II (CNTFET-DO-CCII) is designed and simulated A CNTFET based trans linear DO-CCII is proposed by A. Imran [12] uses 32 nm technology node using 19 transistors. However, this CNTFET based trans linear DO-CCII suffers from very low band width, low voltage linearity range, very high port resistances, and so forth. Further, Imran have not developed any application for the proposed circuits The key performance parameters of CNTFET which is a wonderful material, considered as the fourth allotrope of carbon, CNT (carbon nanotube wall), is discovered by Sumio Iijima of Japan in 1996 and independently by Donald Bethune in 1993. CNTs are of two types, single wall and multi wall. They are graphite sheets with cylindrical shape-based DO-CCII has been further optimized by varying various CNT parameters, like N, S, and D_{CNT}. Lastly, some applications like oscillator, Integrator and differentiator have been designed by using proposed versions of DO-CCII. It has been seen that the proposed CNTFET-DO-CCII, are having the Key Parameters of CNTFET which are discussed.

The performance of CNTFETs is influenced by several critical parameters are Number of CNT (N) determines the current-carrying capacity, CNT Diameter (D_{CNT}) affects the bandgap and electrical properties, Inter-CNT Pitch (S) the distance between the centers of two adjacent CNT, Chiral Indices (n, m) define the CNT electronic properties (metallic or semiconducting), Inter-Atomic Distance the distance between neighboring carbon atoms is 0.142 nm .

TABLE I. SIMULATION PARAMETERS OF CNTFET

Oxide Thickness (T_{ox})	4 nm
Dielectric Constant	16
Mean-Free-Path	200 nm
CNT Diameter (D_{CNT})	1.5 nm
Chirality	(19, 0)
Number of CNT (N)	9
Inter-CNT Pitch (S)	20 nm

The diameter of a CNT and the width(W) of a CNTFET are determined by the following equations, For (1) the CNT Diameter (D_{CNT}) where a_0 = inter-atomic distance (0.142 nm), m, n = chiral indices and for (2) CNTFET Width (W) where N= number of CNTs, S = inter-CNT pitch.

$$D_{CNT} = \frac{\sqrt{3}a_0}{\pi}\sqrt{m^2+n^2+mn} \quad (1)$$

$$W=(N-1)\times S + D_{CNT} \quad (2)$$

The main abstract is integer order components which are used in CNTFET current conveyor applications oscillator, integrator differentiator like capacitor which are used as feedback elements in proposed circuits. But replacing components with fractional order components like fractional order capacitor, increases the parameters performance of the circuits like bandwidth, frequency, and phase zones.

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PROPOSED STRUCTURE OF DO-CCII

The proposed CNTFET DO-CCII is designed and simulated in cadence virtuoso at 32nm technology node and the CNTFET files are extracted from Stanford university website which is Verilog-a code and the following simulation parameters are shown in Table I.

The symbolic representation of CNTFET DO-CCII states that $V_X = V_Y$ states the voltage at port X follows the same voltage at port Y and $I_Y = 0$ it represents that due to high impedance at port Y the current drop is zero and $I_{Z^+} = +I_X$ and $I_{Z^-} = -I_X$ so this both equations conveys that the current at port X is transferred to Z^+ and the current at Z^- is the inverted version of I_X. The unique features of DO-CCII include (a) R_{IN}= ∞ at port Y, (b) R_X= 0 at port X for current inputs

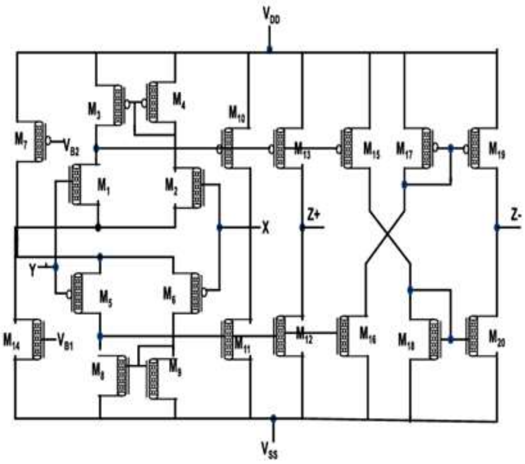

Fig. 2.Schematic of proposed structure DO-CCII

(c) R_{OUT}= ∞ at port Z, (d) current gain between ports X and Z is unity, (e) voltage gain between ports Y and X is unity, (f) Infinite band width

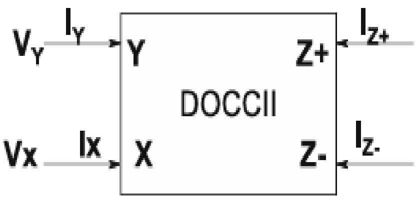

Fig. 3.Symbol of CNTFET dual output-second-generation current conveyor (DO-CCII)

The following schematic of proposed CNTFET DO-CCII has different functions for each pair of section which is discussed in the below Table II and stating the operating voltages at which DO-CCII Operates at $V_{DD} = 1.2v, V_{SS} = -1.2v$ and biasing voltages $V_{b1} = 1v$ and $V_{b2} = -1v$ making it suitable for low-power designs. Based upon the proposed schematic of CNTFET DO-CCII it is built by using different types of functional blocks like differential pairs, biasing transistors, current mirrors.

TABLE II. CNTFET-BASED DO-CCII CIRCUIT MAJOR BLOCKS AND FUNCTIONALITY

Sno	Major Blocks and Functionality	n-CNTFET	p-CNTFET
1	Differential Pairs (Ensure voltage at Y is followed at X)	M1, M2	M5, M6
2	Biasing Transistors (Provide bias current to differential pairs)	M14	M7
3	Current Mirrors (Maintain equal currents and reflect from X to Z)	M8 (source), M9 (sink)	M3 (source), M4 (sink)
4	Output Current Swing	M11	M10
5	Current Copy from X to Z	M12	M13
6	Current Inversion for Z port	M16, M18, M20	M15, M17, M19

The aspect ratio of CMOS-DO-CCII is chosen in such a way to satisfy the desired characteristics of the DO-CCII. Table III show that the aspect ratio for all the CNT transistors is constant. This is attributed to the fact that the n and p type CNTs have same mobility. The width, W of all the CNTFETs used is calculated from (2). The number of CNTs are taken as N = 9, Inter spacing distance pitch, S is considered as 20 nm and diameter, D_{CNT} = 1.5 nm and for the chirality (19, 0).

TABLE III. ASPECT RATIO FOR TRANSISTORS

Sno	Transistor	W/L(CNTFET-DO-CCII)
1	M1, M2	0.161 μm/32 nm
2	M3, M4, M10, M11	0.161 μm /32 nm
3	M7, M14	0.161 μm /32 nm
4	M8, M9	0.161 μm /32 nm
5	M5, M6, M12, M13, M15, M16	0.161 μm /32 nm
6	M17, M18, M19, M20	0.161 μm /32 nm

III PROPOSED INTGER ORDER CNTFET DO-CCII

In this section, we have discussed the applications based on the proposed CNTFET which are have been developed.So, sinusoidal oscillators,integrators and differentiators based on the CNTFET-DO-CCII have been developed

SINUSOIDAL OSCILLATOR

The circuit diagram of a sinusoidal oscillator based on the proposed CNTFET is shown in Fig5 . This oscillator circuit developed with two DO-CCII and two grounded capacitors. The main advantage of this oscillator circuit is that it is resistor less and has no floating components. Further, it does not require any component matching condition. The oscillation frequency of the oscillators is given as below

$$f = \frac{1}{2\pi\sqrt{c_1 c_2}}$$

As shown in Fig4 the capacitors $C_1 = C_2 = 1$ pF for oscillator is taken for simulation

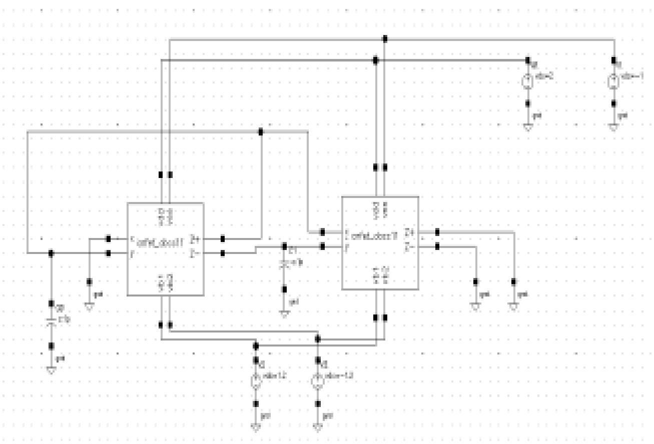

Fig. 4.Schematic for Conventional CNTFET DO-CCII Oscillator

CNTFET DO-CCII Sinusoidal Oscillator is an active analog circuit that generates a pure sinusoidal waveform using current conveyors instead of using traditional op-amps. So, this type of circuits is well used for high frequency operation, low power consumption, and improved linearity.

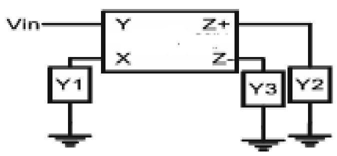

Fig. 5.General block diagram for convential CNTFET based DO-CCII integrator and oscillator

INTEGER ORDER CNTFET DO-CCII BASED INTEGRATOR AND DIFFERENTIATOR

An integrator is an Analog electronic circuit that is used to mathematically integrate an input signal. It gives an output that is directly proportional to the time integral of the input voltage

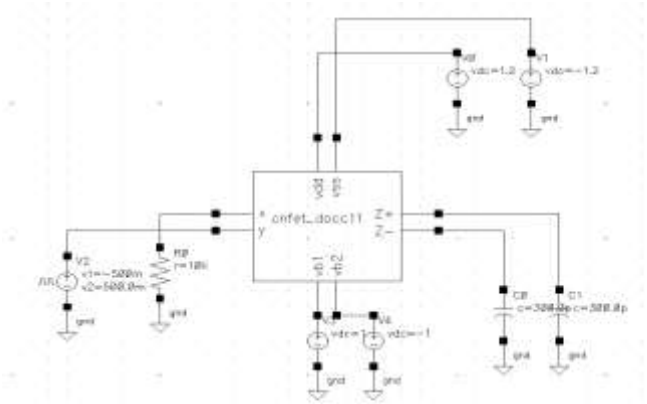

Fig. 6.Schematic for Ineger order CNTFET based DO-CCII integrator

From Fig5 Y2 and Y3 are considered as a capacitor and Y1 is considered as a resistor. Here in Y1 =10KΩ and Y2=Y3=0.5nf are used in simulation. Output voltage at Z^+ terminal V_{Z^+} is expressed as,

$$V_{Z^+} = \frac{1}{Y1Y2}\int V_{in}dt$$

The voltage at Z^- terminal V_{Z^-} is 180^0 phase shifted than that at Z^+.

A differentiator is a circuit in which an analog signal produces an output that is proportional to the rate of change (derivative) of the input voltage. It measures how rapidly the input signal changes in simpler terms. In differentiator circuit if Y2, Y3 are considered as resistors and Y1 as a capacitor. From Fig5 in simulation Y1 = 0.1nF and Y2 = Y3 = 1.5 KΩ. The voltage at Z^+ terminal of the differentiator is given as

$$V_{Z^+} = Y1Y2\frac{dV_{in}}{dt}$$

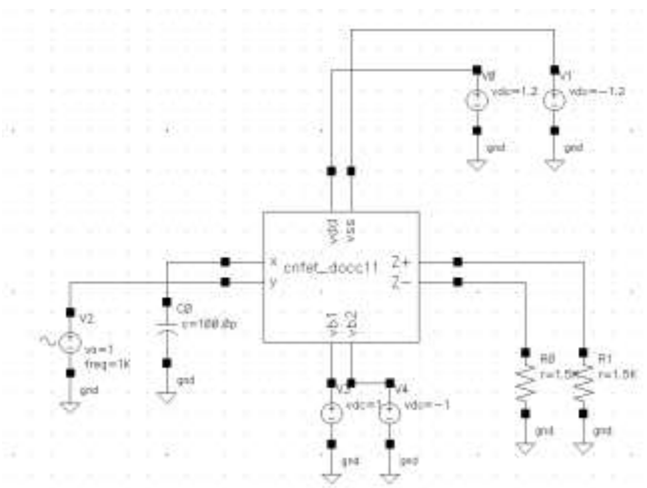

Fig. 7.Schematic for Intger order CNTFET DO-CCII differentiator

IV PROPOSED FRACTIONAL ORDER CNTFET DO-CCII APPLICATIONS

A key concept to introduce a fractional order elements to meet the requirements to the real world applications by intoducing fractional order oscillator,differentiator and integrator

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FRACTIONAL ORDER SINUSOIDAL OSCILLATOR

To design a Fractional order Sinusoidal oscillator we have to design a 5th order Foster RC network.In the above CNTFET DO-CCII sinusoidal oscillator from Fig5 the capcitor Y2=1pF is replaced by Fractional order capacitor with the concept 5th order Foster RC network.Designing it at a frequency of 100Mhz.Generally the Foster type RC network is based on modelling an impedance (or) admittance using a ladder of RC pairs and 5 stage RC network each with capacitance 1pF and the resistor networks needed to be determined.And also the network must provide useful attenuation characterstics at 100Mhz.

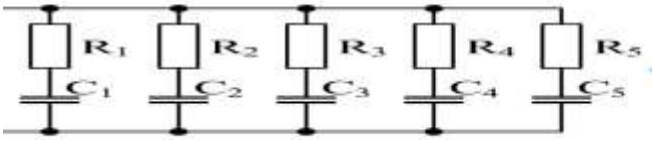

Fig. 8. 5-stage Foster network

At f=100Mhz,the angular frequency ,$\omega = 2\pi f,\ \omega = 2 \times \pi \times 10^8$=$6.28\times 10^8 rad/sec$ and then after we want time constants to span a range around this frequency ,Time period $[\tau] = \frac{1}{\omega} = \frac{1}{6.28\times10^8} = 1.59ns$. Choosing the time constants (τ) in a logarthimic spread around this central value.

TABLE IV. DERIVATION OF R NETWORKS IN 5TH ORDER RC FOSTER

Stage (resistor)	τ(ns)	R= τ/c(in Ω)
1	0.1	0.1/1e-12=1.59k
2	0.3	0.3/1e-12=15k
3	1.0	1.0/1e-12=159.15k
4	3.0	3.0/1e-12=1.59M
5	10.0	10/1e-12=15.9M

For Fractional order Sinusoidal oscillator the 5th order foster network has from $C_1$to C_5=1pF and $R_1 = 1.59k$, $R_2 = 15k, R_3 = 159.15k, R_4 = 1.59M, R_5 = 15.9M$

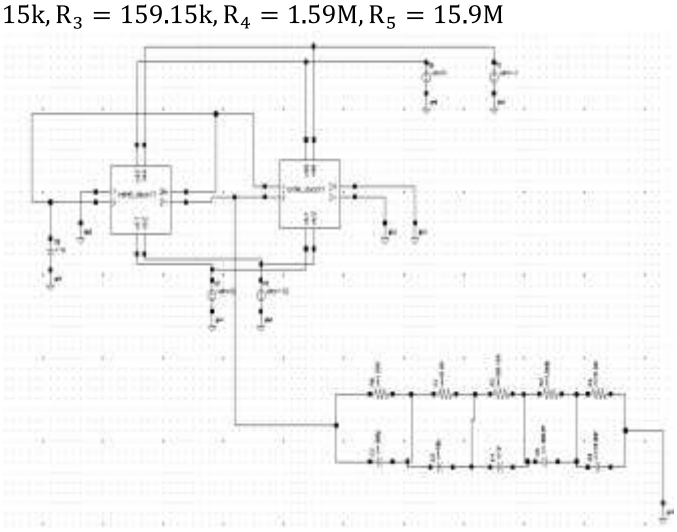

Fig. 9.Schematic for Fractional order CNTFET DO-CCII Oscillator

FRACTIONAL ORDER CNTFET DO-CCII BASED INTEGRATOR AND DIFFERENTIATOR

To design a Fractional order integrator we have to follow the same process from above like design a 5th order Foster RC network.so from CNTFET DO-CCII integrator i.e from Fig7 the capcitor Y2=Y3=0.5nF is replaced by Fractional order capacitor with the concept 5th order Foster RC network. To design it at a frequency of 100Mhz. at 5 stage RC network each with capacitance 0.3nF for better simualtion result and the resistor networks needed to be determined.And also the network must provide useful attenuation characterstics at 100Mhz. At f=100Mhz,the angular frequency $\omega = 2\pi f,\ \ \omega = 2 \times \pi \times 10^8$=$6.28\times 10^8 rad/sec$ and then after we want time constants to span a range around this frequency Time period $[\tau] = \frac{1}{\omega}$ = $\frac{1}{6.28\times10^8} = 1.59ns$.

TABLE V. DERIVATION OF R NETWORKS IN 5TH ORDER RC FOSTER

Stage (resistor)	τ(ns)	R= τ/c(in Ω)
1	0.1	0.1/0.3e-9=333
2	0.3	0.3/0.3e-9=1k
3	1.0	1.0/0.3e-9=3.33k
4	3.0	3.0/0.3e-9=10k
5	10.0	10/0.3e-9=33.3k

Fractional order Integrator the 5th order foster network has from $C_1$to C_5=0.3nF and $R_1 = 333$, $R_2 = 1k, R_3 = 3.33k, R_4 = 10k, R_5 = 33.3k$

Designing the 5th order foster RC network components we have to replace both capacitors at feedback output side of integrator with fractional order capacitors.

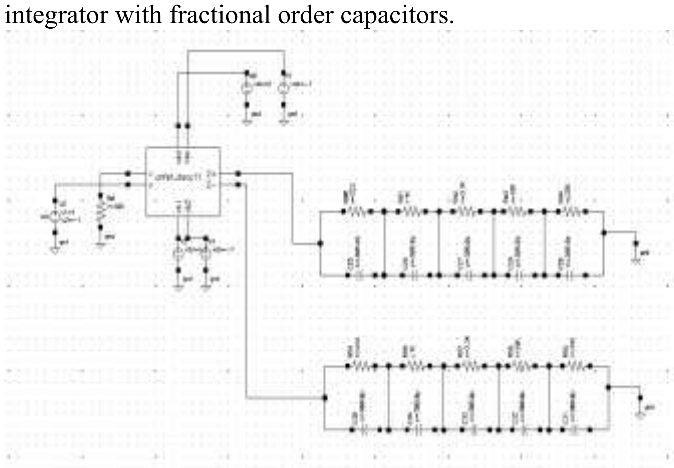

Fig. 10. Schematic for Fractional order CNTFET based DO-CCII integrator

Designing a fractional order differentiator, we must follow the same procedure from the Fig8 Y1=0.1nF must be replaced with fractional order capacitor using 5th order foster RC network. To design it at a frequency of 100Mhz, 5 stage RC network each with capacitance=0.1nF for better simualtion result and the resistor networks needed to be determined.And also the network must provide useful attenuation characterstics at 100Mhz. At f=100Mhz,the angular frequency $\omega = 2\pi f,\ \ \omega = 2 \times \pi \times 10^8$=$6.28\times 10^8 rad/sec$ and then after we want time constants to span a range around this frequency ,Timeperiod $[\tau] = \frac{1}{\omega} = \frac{1}{6.28\times10^8} = 1.59ns$.

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TABLE VI. DERIVATION OF R NETWORKS IN 5TH ORDER RC FOSTER

Stage (resistor)	τ(ns)	R= τ/c(in Ω)
1	0.3	0.3/0.1e-9=3k
2	1.0	1.0/0.1e-9=10k
3	1.59	1.59/0.1e-9=15.9k
4	3.0	3.0/0.1e-9=30k
5	10.0	10/0.1e-9=100k

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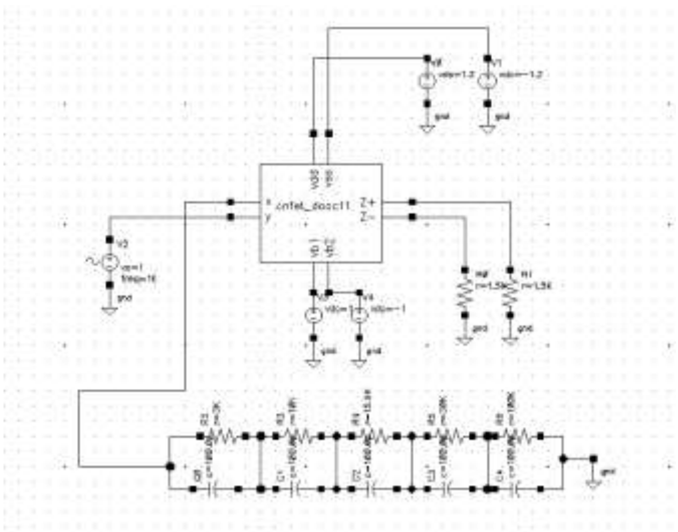

Fig. 11. Schematic for Fractional order CNTFET based DO-CCII differentiator

Fractional order differentiator the 5th order foster network from $C_1$to C_5=0.1nF and $R_1 = 3k, R_2 = 10k, R_3 = 15.9k, R_4 = 30k, R_5 = 100k$

V RESULTS AND DISCUSSIONS

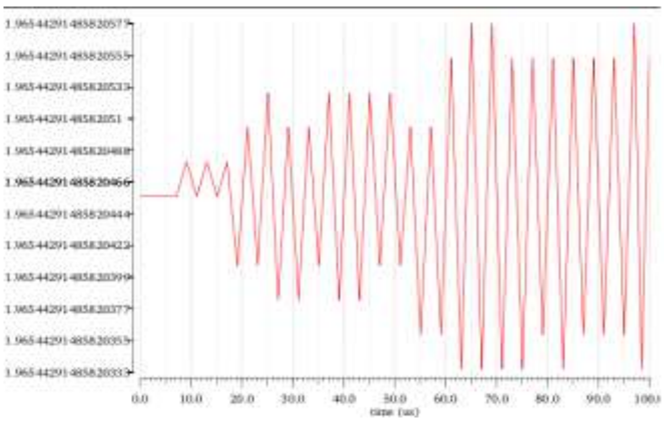

Fig. 12. Waveform for Integer Order CNTFET DO-CCII Oscillator

Sinusoidal oscillations provided by integer order CNTFET current conveyor at the frequency of 60Mhz which is showing oscillation in $60\mu s$ and it is cicuitary is shown above in Fig5 and they don't have wider phase zones or constant phase zones.

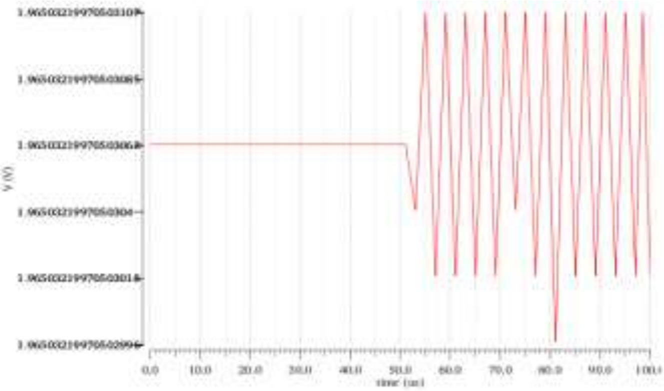

Fig. 13. Waveform for Fractional order CNTFET DO-CCII Oscillator

Sinusoidal oscillations provided by fractional order CNTFET current conveyor at the frequency of 66Mhz which is showing oscillation in $66\mu s$ and it is cicuitary is shown above in Fig9 and they have wider phase zones (90°)

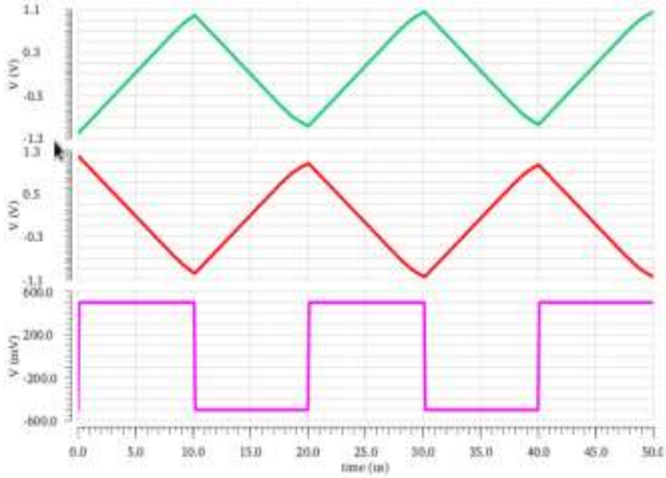

Fig. 14. Waveform for Integer order CNTFET DO-CCII integrator

When the applied input as square wave to integrator then the output is triangular wave. The observation at Z^- terminal the triangular wave is inverted compared to output at Z^+ terminal. Regarding the Fig7

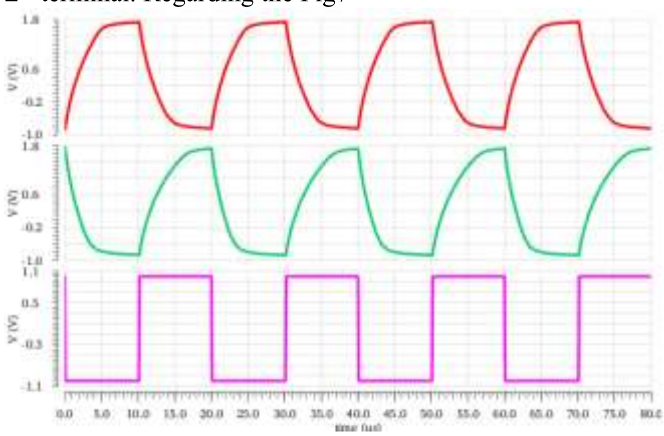

Fig. 15. Waveform for Fractional order CNTFET DO-CCII integrator

For Fig15 When the applied input as square wave to integrator then the output is triangular wave. The observation at

Z^- terminal the triangular wave is inverted compared to output at Z^+ terminal.
Regarding the Fig10 but they have wider phase zones (90°)
And better bandwidth.

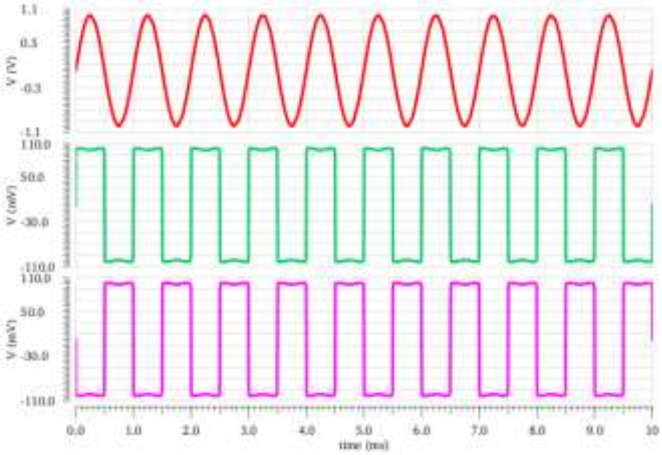

Fig. 16. Waveform for Integer order CNTFET DO-CCII differentiator

For Fig16 When applied input is sin wave to differentiator then the output is cosine wave. The observation at Z^- terminal the cos wave is inverted compared to output at Z^+ terminal. Regarding the FIG8 here the main reason for CNTFET differentiator is due to high performance of CNTFET speed and low power consumption and used so many applications like designing High-Frequency Voltage-Mode Differentiator Using CNTFET CCII. So, regrading for Fig17 When applied input is sin wave to differentiator then the output is cos wave. The observation at Z^- terminal the cos wave is inverted compared to output at Z^+ terminal. Regarding the Fig11 but they have wider phase zones(90°) and better bandwidth.

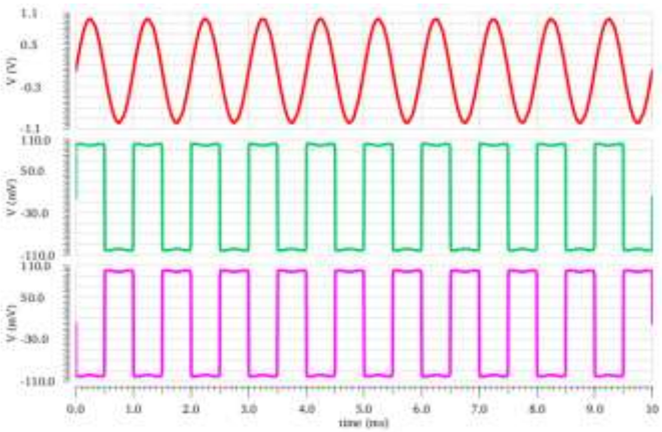

Fig. 17. Waveform for Fractional order CNTFET DO-CCII differentiator

TABLE VII. COMPARISION PARAMETERS BETWEEN INTEGER CNTFET DO-CCII AND FRACTIONAL ORDER CNTFET DO-CCII

S.no	Application	parameter	Integer order CNTFET DO-CCII	Fractional order CNTFET DO-CCII
1	oscillator	frequency	60 Mhz	66 Mhz
2	Integrator	Bandwidth and phase Zone	80Mhz & 45–90°	100 Mhz&90°
3	differentiator	Bandwidth and phase Zone	90 Mhz& 45–90°	120 Mhz&90°

This comparision table states the major differences in terms of frequency,bandwidth and phase zones that there is more development in Fractional order CNTFET DO-CCII than Integer Order CNTFET DO-CCII

VII CONCLUSION

Concluding that due to introduction of fractional order elements like fractional order capacitor in place of Integer order elements like capacitor and inductor for CNTFET DO-CCII applications like oscillator,differentiator, integrator we can state that there is an improvement in frequency,bandwidth,and maintaining constant phase zones and they are used in real-world applications like Analog signal processing (high-speed differentiators), Biomedical signal analysis, High-speed data conversion, RF and microwave analog front-ends ,Neuromorphic systems.

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