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Design and Simulation of Carbon Nanotube Field Effect Transistor based Low Pass Filter

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Abstract

Carbon nanotube is the new material which has ability to replace Si in the future. CNT has remarkable unique properties that make carbon nanotube a promising material in the future. Carbon nanotube field effect transistor is one of the main application of CNTs. Carbon nanotube Field Effect Transistor will play important role in designing of sequential and combinational circuits which are the base of digital computers. Carbon Nanotube Field Effect Transistors have been considered as accompaniment to , future electronic circuit due to the larger current carrier mobility in CNTs compared to bulk silicon. In this research paper, simulation of Low Pass Filter have done at 45 nm technology using hspice. The simulation result of proposed Carbon Nanotube Field Effect Transistor based Low Pass Filter show that the frequency response of Low Pass Filters are working satisfactory. It has applications in the low pass circuits. In electronics, these filters are widely used in many applications. Moreover, it is clear from the Phase response of Carbon Nanotube Field Effect Transistor based Low Pass Filter that it is stable Filter. So, we can use it in powerful conditions where stability is main concern.

Keywords: *CNTFETs, Low Pass Filter, Simulation, Frequency Response, Active filters*

1. Introduction

The first MOSFET is invented as early as 1964 and since then, MOSFETs has prevailed in digital application particularly related to modern computers. Metal oxide silicon field effect transistor has been used widely in electronics industries. With the increasing technology, we are scaling down the channel length of MOS which may results in many short channel effects. Due to these conditions operational amplifier is rigorous. Intrinsic gain of the transistor becomes low due to inferior device output impedance. The semiconducting materials industry is facing some major problems at the nanoscale dimension. The challenges are power and performance optimization, device fabrication and control of process changes at nanorange and integration of a diverse set of materials and devices on the same chip.

To get rid of all these drawbacks of conventional MOSFET performance with sustaining Moore’s Law, it is necessary to find out the other solution like CNFETs that gives the better performance than existing MOSFETs. CNFET uses an array of carbon nanotube material instead of Silicon in channel length which are used in MOSFETs. Due to its inert nature it can conduct at the maximum. In CNFET the flow of electrons follows the ballistic transport and the leakage current is very low hence exhibiting excellent performance characteristics over conventional MOSFET. The path of technological advancements has been paved by the scaling down of devices. Dimension of distinct devices in an integrated circuit followed Moore’s law [1]. A great deal of work has been accessible in the writing on the digital applications uses of CNFETs yet its analog

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applications have not been investigated. Remembering the prior, this paper investigates in subtle element the execution of CNFET based low pass filter has done at 45 nm node technology for getting the frequency response of carbon nanotube field effect transistor based low pass filter. The simulation is being done by using hspice. In this research paper, simulation of Low Pass Filter have done at 45 nm technology. The simulation result of proposed Carbon Nanotube Field Effect Transistor based Low Pass Filter show that the frequency response of Low Pass Filters are working satisfactory. Moreover, it is clear from Phase response of Carbon Nanotube Field Effect Transistor based Low Pass Filter that it is stable Filter. So, we can use it in powerful conditions where stability is main concern [33].

The signals like biomedical, with low amplitude and frequency are naturally given outer unsettling influence or noise like signals because of interference. Voltages or currents that have a tendency to degenerate the primary signal, for example, exchanging noise in the system power supply ripple, tend to influence the information present in the signal. Consequently, low pass filters are utilized to expel the undesirable frequency components. By and by, there are various circumstances in which analog continuous time filters are a need. Analog filter circuits give band restricting of the signals before the signals can be sampled for further handling. A transconductance based low pass filter circuit is worked for this reason.

MOS innovation is advantageous for executing OTAs in light of the fact that are intrinsically voltage-controlled current devices. An assortment of CMOS OTAs with various topologies have been created for various purposes.

OTA based active filters are extremely famous attributable to their remarkable components, for example, they have flexible and linear transconductance (g_m) over extensive variety of bias current, give amazing matching betwixt amplifiers, and give high yield signal to noise ratio.

The folded Cascode OTA is one topology of CMOS OTAs. The term folded cascode OTA is inferred by folding down p-channel cascode active loads of a differential combine and changing the MOSFETs to n-channels. We have decided on folded cascode OTA for its huge gain and high bandwidth performance furthermore has great PSRR contrasted with the two stage operational amplifier since the OTA is repaid with active loads. It has found an expansive use in filters, A/D converters in view of its diminished thermal noise, high gain and conceivable advancement of power utilization. In this area, framework and amusement of novel folded cascode OTAs based CNTs has been performed. CNT based folded cascode Op Amp results in high performance than conventional CMOS based folded cascade Op Amp in DC voltage gain, average power [32].

This paper begins with an overview of Carbon Nanotube and Carbon Nanotube Field Effect Transistors (CNFET) in Section 2. Section 3 covers CNFET based low pass filter. Section 4 gives Result & Discussion. Section 5 describes conclusion.

2. CNT and CNFET

In 1991, Iijima first observed that carbon nanotubes assembles a macromolecular class with one of a kind thermal, mechanical and electricity properties. Carbon nanotubes (CNTs) are a standout amongst the most encouraging applicant that may offer an answer for a portion of the issues specified previously. Carbon nanotubes may be either metallic or semiconducting based on the arrangement of carbon atoms decided by their Chirality, which suggests their probable for fairly different nanoelectronic applications. The semiconducting Carbon Nanotubes, with their elevated current densities and the deficiency of interface states, in comparison with the silicon/Silicon dioxide interface, would be perfect candidates to replace silicon in future transistors. In fact, it has already been expressed that CNFETs can have a performance superior to the most advanced silicon MOSFETs [2-3]. Roused by the fullerene investigate, various exploration groups hypothetically watched a hypothetical carbon structure consisting of a single layer of graphene sheet rolled into a tube that resembles a extended fullerene molecule – SWCNT [4-6]. Some exciting properties were forecasted for Single Wall Carbon Nanotubes, for example that they should be either semiconducting or metallic and behave like 1-D conductors. Single Wall Carbon Nanotubes were invented after a short time, in 1993.

Now in order to ensure further development in Field Effect Transistor performance as per the Moore's Law, it is necessary to consider for alternative like CNFETs that pledge to provide much better performance than existing MOSFETs. Carbon Nanotechnology Field Effect Transistor can also be easily shared with the mass CMOS technology on a single chip and uses the same foundation. A single walled carbon nanotube is a 1D conductor, that can be either metallic or semiconducting dictated by the course of action of carbon atoms chose by their Chirality, C_h (*i.e.*, the direction in which the graphene sheet is rolled).The magnitude of Chirality, C_h and the relationship of C_h with Carbon Nanotube diameter is given by Eqs.(1) and (2) respectively where "a" is known as graphene lattice constant whose value is 0.249nm and n_1, n_2 are positive numbers that determine the chirality of the tube [7-14].

$$C_h = a\sqrt{(n_1^2 + n_2^2 + n_1 n_2)} \quad (1)$$

$$D_{CNT} = C_h/\pi \quad (2)$$

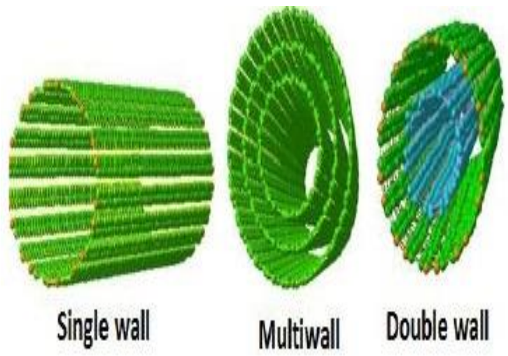

Figure 1. Different Types of Carbon NanoTubes

CNFETs are favourable candidates as augmentation to Si CMOS due to marvellous CV/I device performance [15-16]. CNFETs can be classified as either Schottky Barrier controlled FET or MOSFET-like FET [17-19] according to the operation mechanism. Considering both the fabrication feasibility [20] and superior device ac performance of the MOSFET-like CNFET, can be used, as compared to the SB-controlled FET, MOSFET-like CNFETs are used for the performance evaluation.

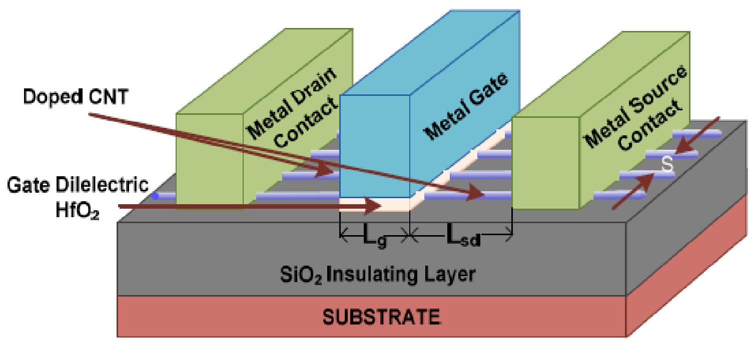

Figure 2. Physical Structure of the CNFET with Multiple Tubes

3. CNFET based Low Pass Filter

Folded OTA based first order active low pass filter are clarified utilizing the linearity of transconductance of OTA with bias current. We have decided on folded cascode topology because of its huge bandwidth and high gain. One more explanation behind utilizing OTA rather than Op-Amps is that the frequency in the OTA can be shifted as per the bias current which is controlled by the differential input voltage. Though if there should arise an occurrence of Op-Amps the frequency is changed by differing the size of the capacitor which is the significant downside of Op-Amps in high frequency applications as the size of the capacitor will increase and thus making the circuit cumbersome.

The Figure 3, shows the schematic of a conventional folded cascode operational-amplifier using a class AB output buffer. The load of the operational - amplifier is a 1 pF capacitor, in the frequency response of the operational - amplifier. The Figure 4, shows the circuit diagram of CNT based Folded Cascode Operational Amplifier. CNT based folded cascode Op Amp results in high performance than conventional CMOS based folded cascade Op Amp in DC voltage gain, average power. [32].

We have analyzed CNFET based low pass filter's frequency response.

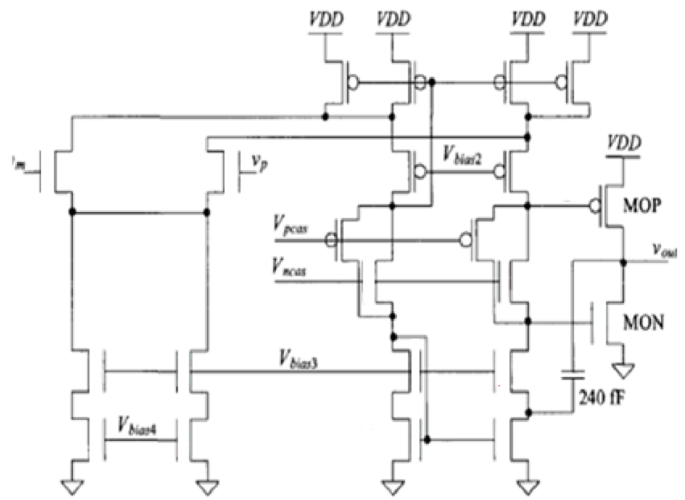

Figure 3. Conventional Folded Cascode OP-AMP

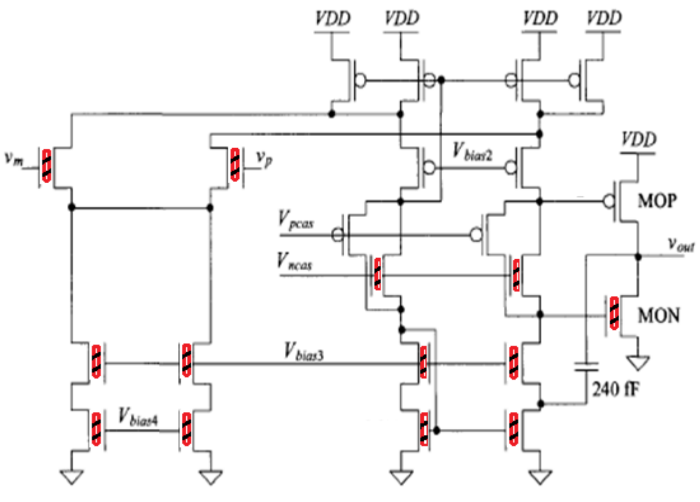

Figure 4. PMOS-NCNT-FC-OP-AMP

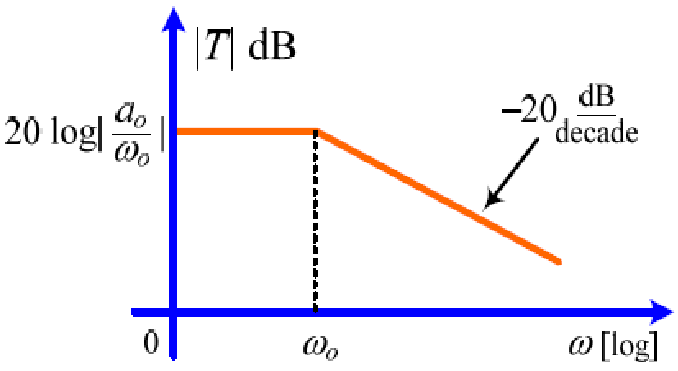

Figure 5. First-Order LPF-Bode Plot

A first-order all pass channel is a signal handling filter that holds the amplitude of the signal consistent over the craved frequency range while the phase is ordinarily moved between 0° to - 180° or 180° to 0°. It can be connected to the electronic measurements, communications, automatic control and neural network systems. For instance, it used to adjust for other undesired phase shifts that emerge in the system. Different sorts of circuits like oscillators and high-Q band pass filters are additionally acknowledged by utilizing first-order all pass filters. Accordingly, some first-order all pass filters taking into account distinctive design methods have been proposed. All low-pass filters are assessed at a specific cutoff frequency. That is, the frequency over which the output voltage falls lower than 3dB of the input voltage. Truth be told this cutoff rate of 70.7 is not arbitrary, all however it might appear to be so at first look. The cutoff frequency is the frequency at which capacitive reactance in ohms squares with resistance in ohms, in a simple capacitive/resistive low-pass filter. A low-pass filter, appeared in Figure 6, permits low frequency signals and attenuates signals at frequencies higher than the cutoff frequency of filters. Low-pass filters are utilized at whatever point high frequency parts must be weakened from a signal [21-31].

The cutoff frequency of a basic capacitive low-pass filter in Hz is given by:

$$\mathbf{fc = 1/2\pi RC}$$

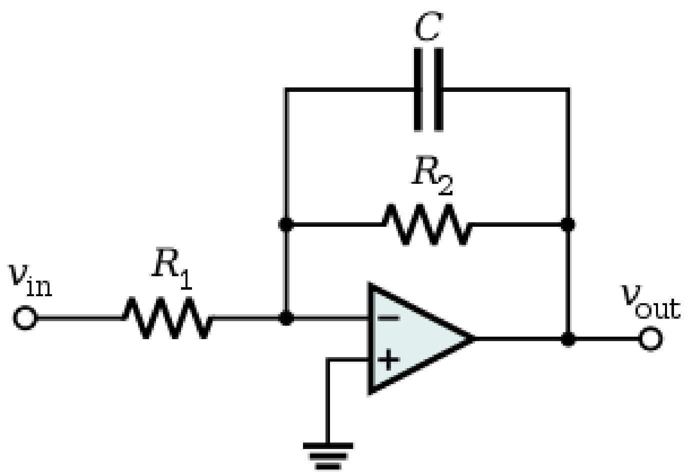

Figure 6. Low Pass Filter

3.1. Simulation Result

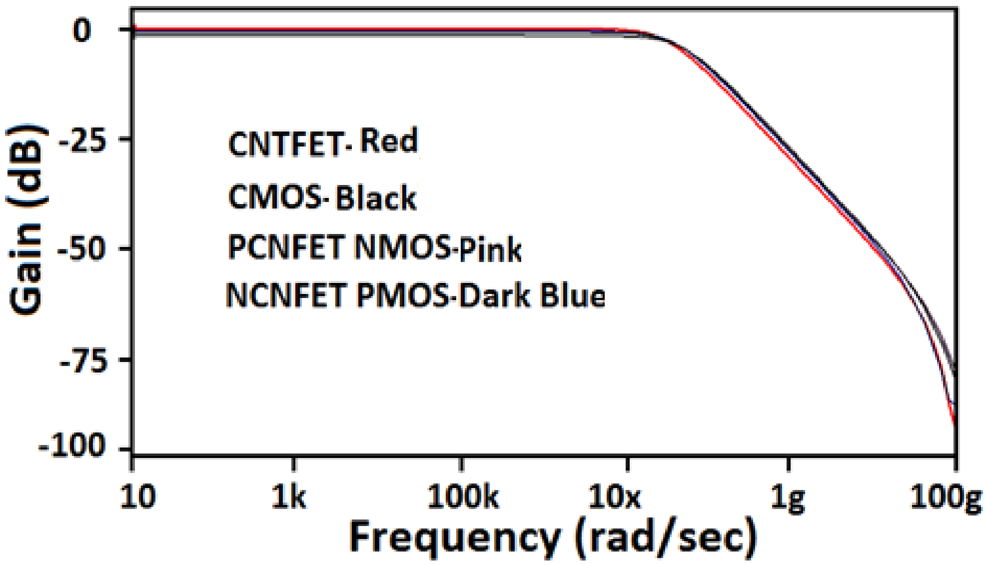

Figure 7. Proposed Low Pass Filter Responses

Table 1. Device Parameters and Process Assumptions for Simulations

Variable Parameters	
Source / Drain Doping Level	0.59 eV – 0.75 eV (0.7% - 1.3%) Uniformly distributed*
CNT Diameter	1.2 nm – 1.8 nm Uniformly distributed*
Probability of a CNT to be Metallic	8% - 32%
Fixed Parameters	
Oxide Thickness (T_{OX})	4 nm
Gate Dielectric(Dielectric Constant:K_{OX})	HfO_2 (16)
CNT Pitch	4 nm
Power Supply	0.9 V
Mean Free Path : Intrinsic CNT	200 nm
Mean Free Path : Doped CNT	15 nm
Gate/Source/Drain Length (CNT)	32 nm
Work Function : contact (φ_M)	4.5 eV
Work Function : CNT (φ_{CNT})	4.5 eV
Interconnect Capacitance	0.22 fF/ μm

Figure 7, displays the frequency responses of the proposed Carbon Nanotube Field Effect Transistor based Low Pass Filter. The performance of the proposed Carbon

Nanotube Field Effect Transistor based Low Pass Filter is confirmed from hspice simulation results.

It is clear the simulated results match the original characteristics of Low Pass Filters.

4. Results and Discussion

In this research paper, simulation of Carbon Nanotube, Field Effect Transistor based Low Pass Filters have done at 45 nm technology using hspice. We have simulated Low Pass Filter. It is clear the simulated results match the original characteristics of Low Pass Filters. It can be used in the low pass circuits applications. Moreover, its phase response shows that it is stable amplifier. So, we can use it in powerful conditions where stability is main concern. Moreover, it show that power consumption is very low (in nano watts) in the Carbon Nanotube Field Effect Transistor based Low Pass Filter. The performance is not degraded due to low power supply *i.e.,* 0.9V. This paper also investigates the analog applications of carbon nanotube based circuits for electronic circuits.

Moreover, role of Carbon Nanotube based Folded Cascode operational amplifier which is having applications in diverse electronic circuits such as filters, integrators, differentiators *etc.,* The low voltage applications and lower dissipation at nano scale is a extraordinary revolution in the work.

5. Conclusion

In this paper , the performance of the Carbon Nanotube Field Effect Transistor based Low Pass Filter is analyzed using hspice. The frequency response of Carbon Nanotube Field Effect Transistor based Low Pass Filter is better than the conventional CMOS. It is clear the simulated results match the original characteristics of Low Pass Filters. It can be used in the low pass circuits applications. Moreover, Phase response of Carbon Nanotube Field Effect Transistor based Low Pass Filter shows that it is stable Filter. So, we can use it in powerful conditions where stability is main concern. Moreover, it show that power consumption is very low (in nano watts) in the Carbon Nanotube Field Effect Transistor based Low Pass Filter. The performance is not degraded due to low power supply *i.e.,* 0.9V.

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