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Efficient RF-to-DC Converters for Biomedical Implantable Devices

Mohd. Tauheed Khan[1]*, Naresh Kumar[2], Aditi Malhotra[3], Aparna Marwah[4], Daljeet Singh Bawa[5]

[1]*Department of Computer Science, Faculty of Engineering and Informatics, Ala-Too International University, 720048, Bishkek, Kyrgyz Republic ORCID: 0009-0005-5698-3194 Email: khan.mohdtauheed@alatoo.edu.kg*
[2]*Deenbandhu Chhotu Ram University of Science and technology Murthal Sonipat Haryana*
Email id nareshkumar.ee@dcrustm.org
[3,4,5]*Assistant Professor Bharati Vidyapeeth (Deemed to be University) Institute of Management & Research - New Delhi*

**Corresponding author's E-mail: tauheed.jmi12@gmail.com*

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Abstract

The power management section associated with the biomedical circuit is very crucial and should be optimally designed for optimal utilization of power. This work discusses the different power shaping or conversion circuits that had been taken for their performance analysis. The two-performance metrics power conversion efficiency and susceptibility against the wireless power transfer have been taken to investigate the operational performance of the biomedical circuits against the input signal strength and operating frequencies. Simulated results confirm the CNFET-based circuit performance is very good at a small value of input voltage 0.6V and a broad range of operating frequency (953 MHz). Therefore, a CNFET-based circuit can be used suitably in implantable devices with optimum power utilization and a remote powering mechanism over the RF link.

Keywords: *Carbon nanotube field-effect transistor, Complementary metal-oxide-semiconductor, Radiofrequency, Full-wave rectifier, Power conversion efficiency*

1. Introduction

In biomedical applications, power consumption is one of the very critical features. Li X (2014) and Mora L (2012) show that the construction of implantable circuits in biomedical devices requires optimization of power at every stage of development such as architectural, circuit, and process design stages (Li X. et al. 2014; Mora L et al, 2012). Irwin, Z.T (2016) told that biomedical hardware optimization decides the device attributes such as speed of operation, consumption of power, and device size, which are highly dependent upon hardware optimization (Irwin et al. 2016).

Motivation

Biomedical devices are getting miniaturization with the arrival of nanoscale. The size of the transistor has already entered the nanoscale regime as per the International technology roadmap for semiconductors (2020). However, at the nanoscale, CMOS technology faces substantial obstacles such as random-dopant-fluctuation, tunneling, short-channel-effect, and roughness of line edge. As a result, non-CMOS technologies having the potential to supplement or replace CMOS must be investigated and be able to meet these challenges shortly. Avouris P (2007) found that the CNT is a valuable material with outstanding qualities such as ballistic carrier transfer, increased electrical and thermal conductivity, and high tensile strength, among others (Avouris P et al. 2007). McEuen, P.L (2002) earlier exploit the CNT-based transistor channel transport and carrier mobility which is better than Bulk CMOS technology, for considerable speed improvements (McEuen, P.L et al. 2002). It is generally known that accelerated speeds of CNFET can be adjusted to obtain lower power consumption. Apart from the higher speed, the CNFET transistor has a lower threshold voltage than the CMOS transistor and therefore, consumes less power and can work effectively at lower input voltage. Therefore, this work aims to exploit the CNT characteristics along with remotely powering the implantable circuit.

2. Literature Review

The literature review covers the kinds of literature on energy harvesting for wireless power transfer and the CNTFET based circuits. Energy harvesting from the neighbor is an answer to delivering a continuous supply to the implantable biomedical circuit. The researchers are looking for different energy harvesting techniques and their transmission over the wireless to the implantable medical devices. Zhang, K (2009) reviewed "in-body" energy harvesting (Zhang et al. 2005) and P. Priya S (200008) reviewed "out-of-body" energy transfer methods (Priya S. et al. 2008) and their practical applications. Ahmad, Hannan M.,(2014) discuss the issues and challenges faced by different methods of energy harvesting in biomedical devices (Ahmad H. M. et al. 2014). Whereas Nattakarn, W (2018) proposed a CMOS-based circuit that is excited with a photon for energy harvesting and delivering the energy to the bio-implants (Nattakarn, W et al. 2018).

Yeon, P (2016) suggested a proper design approach to transmitting the power wirelessly to the implanted devices of millimeter-sized (Yeon, P et al. 2016). Gore, V.B. (2016) suggests a magnetic coupling-based wireless power transmission system, claiming that magnetic resonant coupling is safe for powering implanted devices (Gore V.B. and Gawali, D.H 2016). Whereas the problem associated with a wireless power transfer system is investigated by Das R (2016) for a leadless pacemaker (Das, R. et al. 2016). A thesis of Zargham M (2014) investigates the integration of an implantable device and wireless power transfer system on the same chip (Zargham M. et al. 2014). This power transfer systems integration includes the design of coupling coils with different geometry used for the power transfer. It also discussed in detail the power shaping circuit, its analysis, and optimization. These pieces of literature provide the different aspects of wireless power transfer and their advantages and disadvantages

Alidoosti B (2015) said that the CNTs have many appealing properties, including ultra-lightweight, excellent mechanical strength, ordered structure with a large aspect ratio, high conductivity, high carrier mobility, good electrical conductivity, metallic or semi-metallic behavior, and a large surface area (Alidoosti B et al. 2015). Therefore, CNFETs can be utilized as an important competitor in an extensive range of applications in several fields including electronics. By and by, Mehar bani YS (2017) also told that the CNFET devices were found to show attributes like Si-based MOSFETs (Mehrabani Y.S et al. 2017). Ahmad HMN (2014) proposed a potentiostat that is used for biomedical sensing (Ahmad, HMN, et al. 2014). This CNFET based potentiostat at the 32 nm technology node uses different input voltages to verify the performance of the voltage follower. Puri A (2018) presents CNFET based low-power two-stage OP Amp for biomedical analogy to digital converter (Puri A. et al.2018). Simulation results of MOSFET-based circuits and CNTET based circuits are compared and found a significant improvement in power consumption by up to 80%. These pieces of literature provide the CMOS and CNTFET based circuit performance

Contribution of this work

The performances of the biomedical circuit are being examined under two constraint points: first is its power consumption and the second is the wireless power fidelity of such circuits. The objectives of this work are to design, analyze and review the CNFET based biomedical circuits working in the environment of wireless power transmission at low voltage and compare their performance with corresponding CMOS circuits. This helps to look at the scope of reducing the power consumption of biomedical circuits to an extent that they can be powered through energy harvesting techniques rather than embedded batteries. This will cause a great contribution to the area of implantable electronics. This work investigates the low power potential of CNFET in the domain of biomedical circuits which are getting power supply externally through wireless power transmission techniques. Keeping these in mind, we investigate the performance of the following CNFET based biomedical circuits.

i. CMOS and CNFET rectifier with bootstrapping capacitor

ii. Fully Crossed Coupled CNFET based rectifier

iii. CNFET converter with an auxiliary clamper circuit

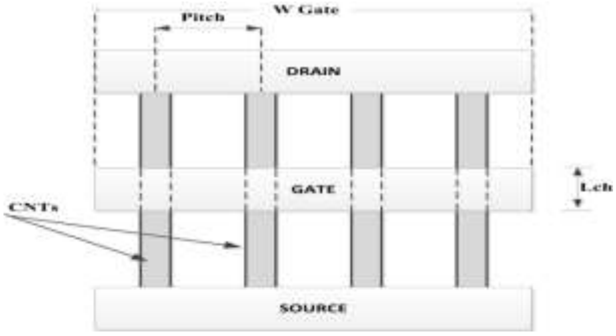
To address these objectives the simulation of CNFET based biomedical circuits have been carried out and their performance is compared with CMOS counterparts. This work also investigates the working of these biomedical circuits for wireless power transmission and found that the circuit functions well even beyond 950 MHz of operating frequency. Therefore, the contribution of this work is to review different power conversion circuit topologies for biomedical applications concerning the consumption of low power and the wireless power transfer susceptibility in the operating frequency range of 950 MHz and beyond.

Power Constraints in Biomedical Implantable Devices

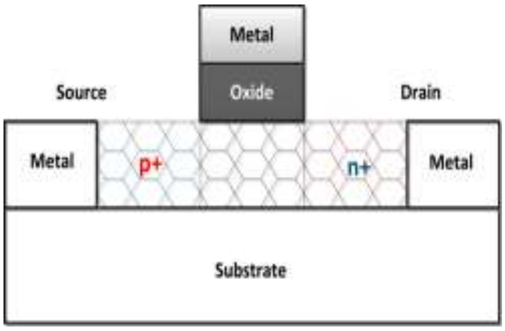
In biomedical implantable devices, embedded batteries and energy harvesting strategies are obliged as far as low energy density, a constrained lifetime of the device, a possible risk to human safety, physical size, trustworthiness, and integration. We propose and discussed two possible solutions to address the power constraints, namely device technological solution and wireless power transmission in this work.

CNFET based implementation

Device technological solution targets the use of CNTFET. An array of semiconducting CNTs is introduced in the channel of traditional MOSFET to obtain a CNFET as shown in Figure 1. Un-doped CNT tubes are used to transmit carriers between the drain and sources. Owing to ballistic transport, these carriers get high mobility since the available free path for charge carriers is larger than the geometry of the device, resulting in the lowering of the carrier's dispersion due to collision. CNFET's superior physical and electrical properties offer better performance than prior silicon-based devices. As a result, biomedical circuits based on CNFETs perform better.



(a)



(b)

Figure 1: CNFET structure (a) Top view (b) Side view

CNFETs model parameters employed in the circuits are given in Table 1 and provided by Stanford nanoelectronics lab (2015), with lattice constant 2.49 Å and chirality (19, 0) (2015).

Table 1: The structural parameter of CNFET

Parameter	Value	Description
n1, n2	(19,0)	Chiral numbers
Dch	1.5nm	Diameter of CNT
Lch	32 nm	Channel Length (Physical)
L_geff	200 nm	Mean free path in a pure semiconductor
T_ox	4nm	Top-gate material thickness
E_fo	0.06eV	Doped CN tube Fermi level in source and drain

In general, biomedical circuits demand low energy consumption to prolong battery life, and CNFET's unique higher speed feature would be used to lower power consumption.

Wireless power transfer

A biomedical implantable device consists of processing circuits, power management circuits, electronic interfacing circuits, and circuits for external communication as shown in Figure 2. Wireless power transmission systems can be considered for powering up such implantable devices continuously and addressing the constraints of limited battery life and harmful wires traveling through the skin. It is also important that circuits of implantable devices must be able to receive wirelessly transmitted power

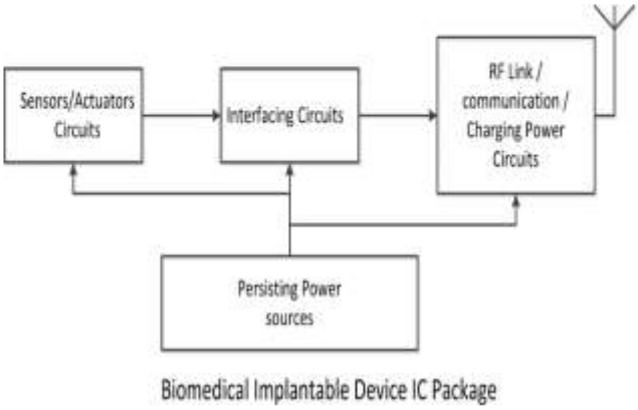


Figure 2: Block diagram of a biomedical implantable device

The energy harvesting system that is widely used in biomedical applications has the inherent property of reduced power consumption, which can be achieved with efficient power conversion circuits. Chouhan, S.S.(2015) demonstrated that the power conversion efficiency (PCE) of a converter is a critical attribute for the converter performance (Chouhan, S.S., and Halonen, K**.**.2015). Almansouri, A.S (2018) and Rosli, M.A (2018) proposed the CMOS-based RF to DC converter circuits among the several proposed CMOS-based converter circuit at different technological nodes (Almansouri, A.S et al. 2018 and Rosli, M.A. et al. 2018**)**.

Researchers are looking for an architecture suitable for energy harvesting applications with a wide range of input signals. Lu, Y (2017) targeted these circuits' suitability in the environment of wireless power transmission (Lu, Y. et al 2017). Xia, M. (2015) and Yedavalli (2017) discussed the far-field powering applications, which rely on radiation power transfer approaches (Xia, M. and Aissa, S 2015 and Yedavalli, P.S et al. 2017) while Jonah H (2013) expressed the non-radiated energy transfer employed for near field power transfer (NFPT) (Jonah, O et al. 2013). These are the two mechanisms for wireless power transmission.

Inductive radio frequency links spread over small distances are the favored method for powering up such implantable devices, as the implanted devices' longevity and the insufficient power efficiencies of embedded batteries are no longer a big deal. However, due to weak electromagnetic coupling, low bandpass, and skin absorption, inductive RF links have quite weak energy transfer efficiency.

An effective power conversion chain (PCC), as given in Figure.3 needs to provide adequate power to the implanted circuit. This power conversion chain should work for the smaller voltage produced in the secondary coil of the inductive RF link. The power conversion chains should have efficient rectifiers, fabricated on the same chip of biomedical circuits and employed to rectify an AC signal for powering up the implantable biomedical circuits.

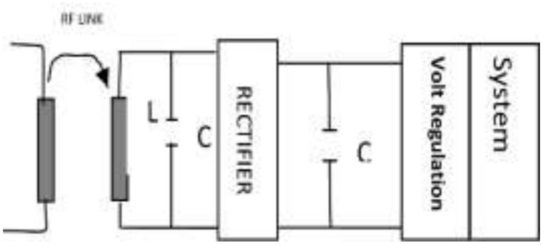


Figure 3: Power conversion chain

The implantable device circuit must be able to receive wirelessly transmitted power and meet the issue of integrated batteries with a limited lifespan and harmful wires through the skins.

Rectifier Circuit Topologies

The usefulness of a full-wave rectifier with a gate cross-coupled gate (GCWR) is given by Kotani K (2009) where input signal can drive the gate of the main path transistor with a higher voltage variation than diode-connected devices, reducing the leakage current and improving conduction (Kotani, K . et al. 2009**)**. This full-wave rectifier (FWBR) topology presents a greater power efficiency than a standard diode-based rectifier structure, yet each source cycle only utilizes a single diode-connected MOS transistor for load connections, hence it suffers from varied (threshold) voltage drop. To handle the issue of threshold voltage loss, the full gate cross-coupled rectifiers are adopted.

The performance parameters of rectifiers such as voltage conversion ratio (VCR), output average voltage, ripple factors, and power conversion efficiency (PCR) are being used for performance analysis. The formulas (3a through 3c) below are used to determine these performance measurements.

$$VCE = \frac{Vout}{Vin} * 100\ (\%) \quad \text{.....................3a}$$

$$PCE = \frac{Pout}{Pin} * 100\ (\%) \quad \text{...................3b}$$

$$Ripple = Vout(max) - Vout(min) \quad \text{....... 3c}$$

Table 2: CNFET attributes

Fully crossed coupled CNFET based rectifier circuits

Two n-type CNFETs (CNN1, CNN2) and two p-type CNFETs (CNP3, CNP4) are used in the CNFET-based gate-crossed coupled rectifier as shown in figure 4. CNFETs employed are of the semiconducting type and have a chiral number (19, 0). To produce the fully-gate crossed coupled; the gate terminals of n-CNFET (CNN2) and a p-CNFET (CNP4) are cross-connected. CNN2 and CNP3 turn on in the positive half of the input signal voltage (Vin), providing a conduction path to the load.

The gate cross-coupled CNFET transistor (CNN2) gives a low resistance path to the load and charges the load capacitor CL. Output voltage (Vout) can be calculated and is equal to the input voltage less than the switching transistor's threshold voltage, as calculated by the below equation (3.1a).

Vout = Vi–Vt (3.1a)

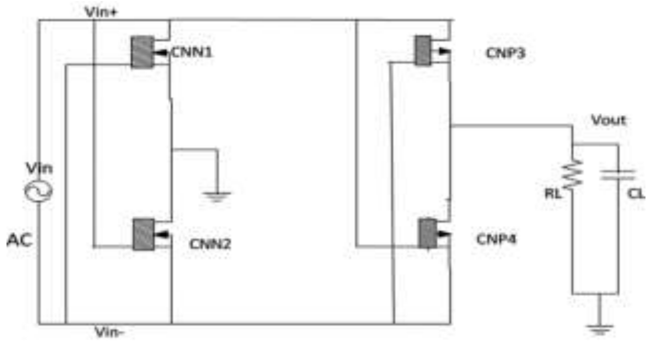


Figure 4: Gate cross-coupled rectifier

Where Vout is an average output voltage across the load, Vi is a peak value of excitation voltage, and Vt is the threshold voltage of the CNFET transistor. During negative cycles of the input excitation voltage (Vi), the transistors CNN1 and CNP4 turn on, while CNN2 and CNP3 turn off, forming a dual-circuit. The presence of a storage capacitor in an antenna or other parasitic device creates a flow-back current, which reduces the structure's power efficiency. As a result, to overcome this difficulty, an additional circuit with bootstrapping capacitors is added.

Voltage converter with bootstrapping capacitors

Hashemi, SS (2012) gives a CMOS-based rectifier circuit with bootstrapping capacitors that show the reduced threshold voltage of the main path switching transistor (Hashemi, SS. et al. 2012). This circuit topology has been taken up for performance analysis and is compared with the CNFET-based full-wave rectifier with a bootstrapping capacitor topology proposed by Khan MT (2018) as shown in Figure 5 (Khan MT et al. 2018). Table 2 lists the CNFET specifications used in the circuit.

CNFET	CNT Number	Pitch between the CNT	Diameter (CNT)
CNN1, CNN2, CNP3, CNP4	150	4nm	1.5nm
CNP5, CNP6	10	8nm	1.5nm
CNP7,CNP8	25	4nm	1.5nm

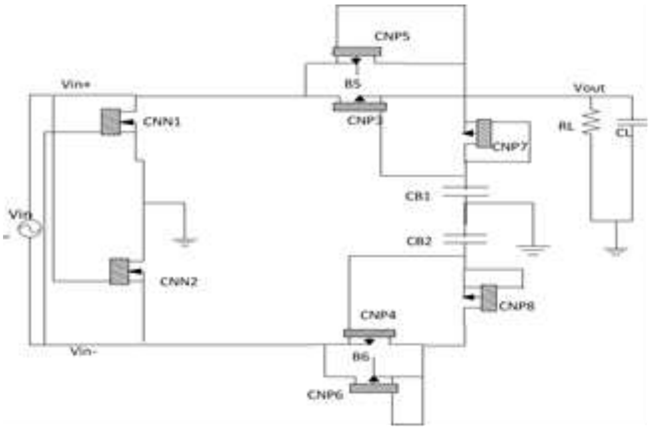


Figure 5: CNFET based full-wave rectifier with a bootstrapping capacitor

The upper portion of the Figure. 5, A capacitor (CB1) and transistors (CNP3, CNP5, and CNP7) make up the bootstrapping circuit. When the applied voltage (Vin) is more than the voltage across the load (Vo), at least by voltage drop (Vt5), the current is flowing via CNP5 and charging load capacitor. For a given fabrication process, transistors of the same type usually have the same threshold voltage. Therefore, the threshold voltages of transistors CNP5 and CNP7 are the same (Vt5=Vt7). The output voltage can be calculated with equation (3.2a).

$$V_O = V_{in} - (|V_{t3}| - |V_{t7}|) \qquad (3.2a)$$

Transistors CNP3 and CNP7 have threshold voltages of Vt3 and Vt7, respectively, and are canceled by each other. Therefore, output voltage is following input voltage because of very less voltage drop. As a result, this bootstrapping technique increases the range of output voltage in the subthreshold region with a very small input voltage (below 1V).

CNFET converter with clamper circuit

Khan M (2019a) proposed a CNFET base converter circuit in which an additional circuit of clamper, whose performance has been evaluated and discussed (Khan, M. et al. 2019a), is suited for application in low voltage implantable devices. This circuit performance is compared with its CMOS counterpart proposed by Mohamed, M.M (2018) for RF power fidelity (Mohamed, M.M et al. 2018).

The architecture shown in Figure 6 has an outside supplementary circuit, when biassed with the RF applied signal, formed a negatively shifted dc voltage level, that is used to bias the primary switching transistor. The gate of the main p-CNFET switch is baised with this shifted negative voltage. The effective power-on voltages of switching transistors (p-CNFET) are reduced with the clamping mechanism. As a result, the rectifying transistor's power dissipation decreases during its conducting state, resulting in enhanced voltage conversion and power conversion efficiency.

The auxiliary circuit's threshold voltage adjustment and the CNFET's leakage reduction are the two fundamental principles used to build this converter. When P-type transistors are used in the biasing circuit, the variable threshold is reduced, improving the PCE of the rectifier circuit at a small input voltage.

An off-chip parallel capacitor of 2pF and a resistor of 10k along with two off-chip coupling capacitors, Cc1 and Cc2 are of 21pF, whereas secondary path coupling capacitances, Cp1 and Cp2 are of 2pF are used in this architecture.

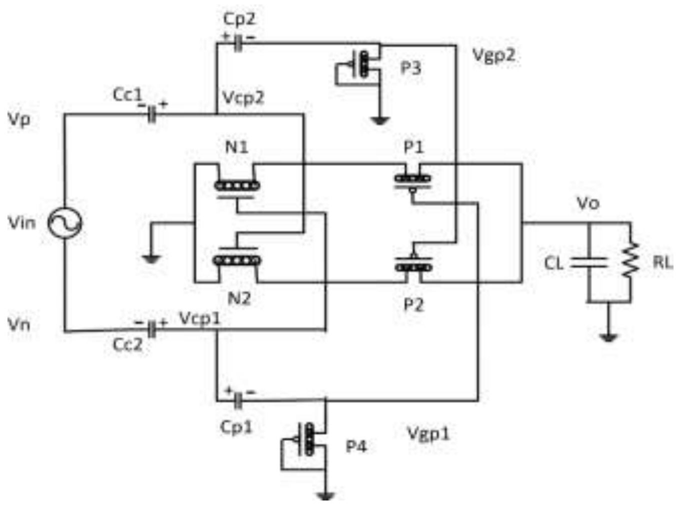


Figure 6: CNFET based rectifier with clamper circuit

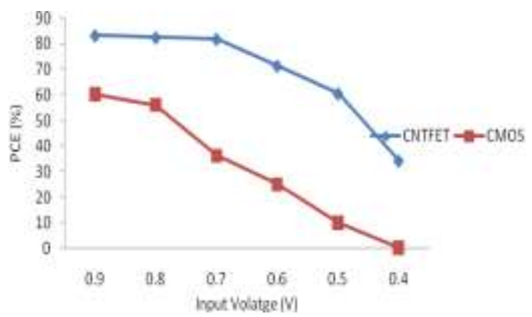
In general, power conversion decreases as the input signal strength decreases. As a result, when the input signal is weak, the input resistance increases, lowering the energy conversion efficiency. However, the proposed architecture performs very well and achieves a high PCE (77.7%) even with a weak input signal (0.6 V). This rectifier circuit's operation has also been verified at high input frequencies (953 MHz). Therefore, this circuit architecture has significantly better power conversion efficiency than that of earlier CMOS architecture.

3. Results and Discussion

Voltage and power conversion efficiencies, average output voltage, and ripples are some of the characteristic attributes that had been taken for performance comparison. The suggested rectifiers' performance is evaluated using the Stanford compact HSPICE compatible CNFET and CMOS PTM models given online (Stanford University CNFET model 2020) and (Predictive Technology Model (PTM), 2020 respectively. The scalability of CNFET technology is superior to that of CMOS technology

Fully crossed coupled rectifier results

The Fully crossed coupled rectifier circuit given by Khan MT (2019) has been taken up for the simulation against the 32nm CMOS and CNTFET models (Khan MT et al. 2018). The results show that the CNFET-based architecture is having superior performance metrics to the CMOS-based circuit. The power and voltage conversion efficiency of CNFET-based rectifier circuits are superior to their CMOS-based equivalents and work well with low voltage (0.6V). The circuit's performance remains good across a wide range of operational frequencies (10-100 MHz). The results are displayed in Figure 7 below.



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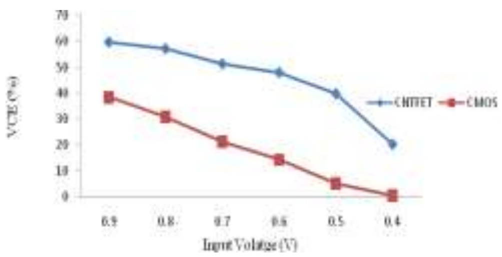

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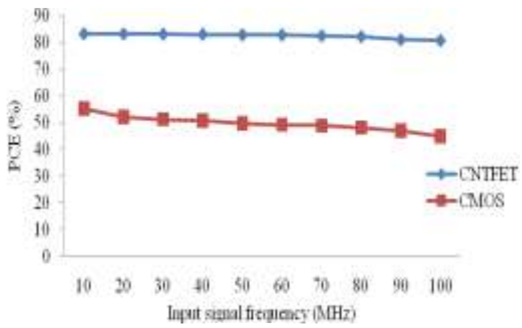

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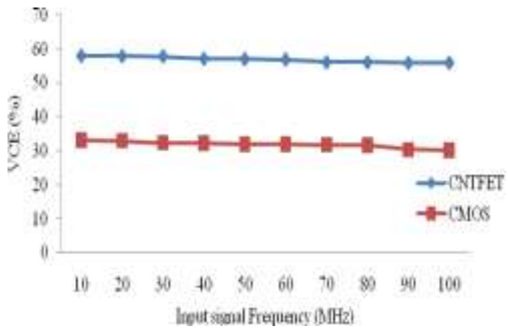


(d)

Figure 7: PCE and VCE variation with input voltage (a)(b) and with operating frequencies (c)(d)

Comparing CMOS-based circuit performance with its CNFET counterparts, it is found that the CNFET circuit shows improved PCE (77.8%) and VCE at low voltage (0.6Volt) and over a wide range of signals frequencies. Therefore, the suggested low-voltage, high-frequency CNFET rectifier architecture can be effectively employed to power biomedical implanted devices wirelessly (through RF Link).

Results of Rectifier circuits with bootstrapping capacitors

The rectifier circuit proposed by Khan MT (2019a) given in Figure 5 has been taken for the performance analysis. The standard CMOS TSMC 0.18 µm, PTM 32nm, and CNFET 32 nm model are used to simulate the circuit to investigate the circuit performance at different technological nodes (Khan MT et al. 2019a).

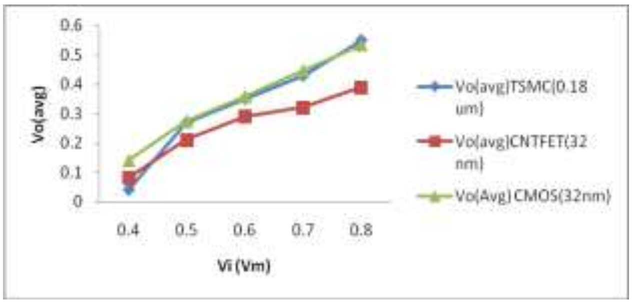
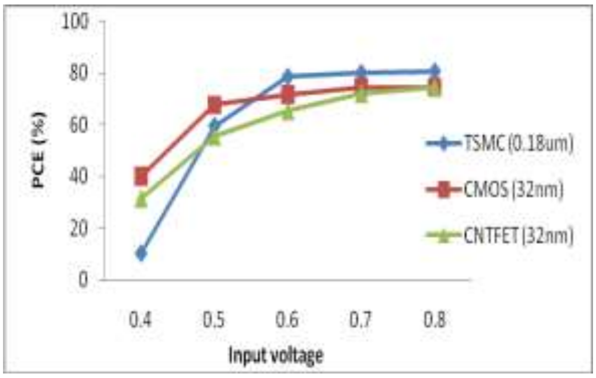


Figure 8: Voltage transfer characteristic



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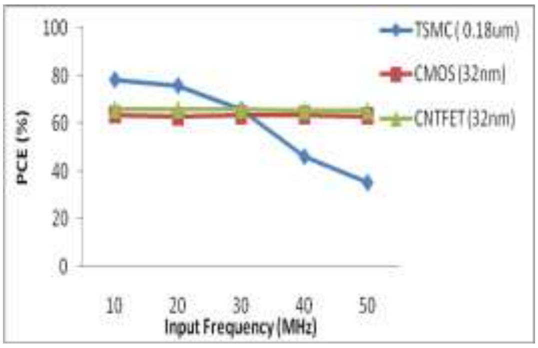


(b)

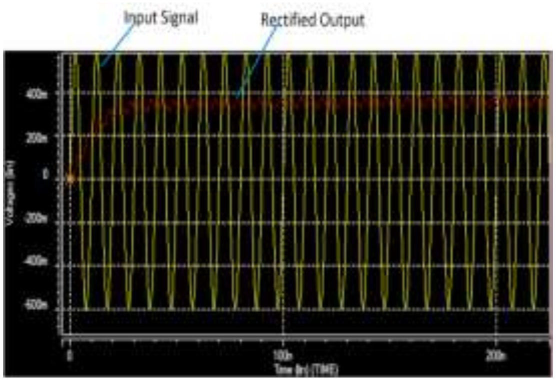
Figure 9: PCE with input (a) voltage signal (b) operating frequency

The performance of the CNFET-based converter and CMOS-based converter as shown in figure 9 is comparable to each other. The performance of this architecture against varying input operating frequencies is superior for CMOS and CNFET at 32nm technological nodes than the CMOS 0.18µm technology. Therefore, the proposed CNTFET circuit is appropriate for use in the implanted device in wireless power transmission environments.

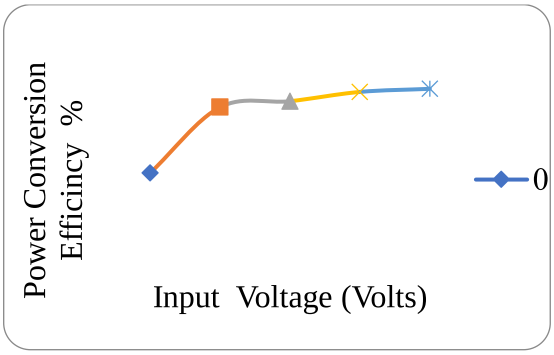
CNFET rectifier with clamper circuit

The CNFET rectifier architecture with a clamper circuit again given by khan MT (2019b) as shown in figure 6 is proposed for the rectification at high frequency (Khan Mohd. T et al. 2019b). The auxiliary circuit provides threshold voltage adjustment to the main switching path of the circuit, while CNFET technology reduces leakage.

Figure 10 shows the output voltage and PCE. The simulated result reveals that this proposed converter has an elevated conversion efficiency of 77% at a very high input frequency (953MHz) at a low input voltage (0.6V). As a result, this circuit can also be used with long-range transmission to power up biomedical circuits remotely.



(a)



(b)

Figure 10: Converter's (a) An average output signal (b) PCE Vs Input signal

The performance and hardware required in the referred CMOS circuit topologies and the proposed CNFET-based rectifier circuits are summarized in Table3. The CNFET based converter with an auxiliary clamper circuit proposed by khan MT (2019b) not only has a very good power conversion efficiency (77.8%) with 2pf on-chip capacitors but also works efficiently in the environment of very high RF frequency (953MHz) at very low voltage (0.6V) (Khan Mohd. T et al. 2019b), compared to its CMOS counterpart given by Mohammad MM (2018) (Mohamed, M.M et al. 2018).

Khan MT (2019a) proposed the CNFET-based rectifier circuit with the bootstrapping capacitor (Khan Mohd. T et al. 2019a). The CMOS-based rectifier proposed by Hasemi SS (2012) is taken for performance comparison (Hashemi, S.S. et al. 2012)**.** The exhaustive simulation result shows that the CNTFET is having comparable PCE to its CMOS counterpart. CNTFET rectifier circuits also work satisfactorily at 100 MHz while the working frequency of the CMOS rectifier circuit is 10MHz. The fully gate-cross coupled rectifier proposed in by Khan MT (2018) has lesser off-chip hardware and improved power conversion efficiency than its CMOS counterpart given by Khan (2017) and Kotani (2009) (Khan Mohd. T et al. 2018; Khan, S.R. et al 2017; and Kotani k et al. 2009).

Table 3: Performance comparison of reported work

Technology	CMOS					CNFET		
	40nm Zöscher et al 2016	**0.18µm** Hashemi SS et al 2012	**0.18µm** Khan SR et al 2017	**0.18µm** Kotani K et al.2009	**0.18µm** Mohamed MM et al, 2018	**32nm** Khan MT et al. 2018	**32nm** Khan MT et al 2019	**32nm** Khan MT et al 2019
Frequency (MHz)	900	10	13.56	953	953	13.56	100	953
Stage (N)	8	1	1	1	1	1	1	1
PCE(%)	42	68	53	67.7	70	77.5	70	77.8
Vin (V)	0.5	0.8	0.7	-	-	0.6	0.6	0.6
Vout	1.2	0.5	0.39	0.6	0.38	0.27	0.28	0.4
RL (KΩ)	250	2	2	10	10	2	2	10
CL (pF)	-	200	200	1.13	2	2	200	2

The CNFET-based; fully gate-cross coupled rectifier by khan MT (2018), rectifier with a bootstrapped capacitor by Khan MT (2019a), and converter with auxiliary clamper circuit by Khan MT (2019b) perform better than their respective CMOS based circuit at low voltage and high operating frequency (Khan Mohd. T et al. 2018; Khan Mohd. T et al. 2019a and 2019b). We also observe that the CNTFET based rectifier given by Khan MT (2019b) does not only have good power conversion efficiency in the radio frequency range (i.e. 953MHz) but also has less off-chip hardware (i.e. 2 KΩ load resistor contrary to 250 KΩ) compared to the CMOS counterpart given by Zöscher L (2016). CMOS circuits work in the radio frequency range of 900 MHz whereas CNTFET works satisfactorily up to 953MHz (Zöscher L. et al. 2016 and Khan Mohd. T et al. 2019b). Low power consumption in a radio frequency environment is very much required in a miniaturized biomedical implantable device for wirelessly powering This results in reduced power consumption and elongating embedded battery life. The reported CMOS-based circuits were mainly developed for 40 nm to 180 nm technological nodes while CNTFET circuits were developed for 32nm technological nodes, resulting in lesser implementation area requirements and hence power consumptions.

It is found that CNTFET converter circuits are not only having good performance in wireless power transmission environments up to 953 MHz but also have better performance at the very low working voltage of around 0.6 Volt. The high speed of carrier transport in CNT can also be traded for the low power consumption. Therefore, the CNTFET converter circuits are a very promising candidate to use in biomedical implantable devices where embedded batteries have limited power backup because of low power consumption and can be recharged over the radio frequency inductive link.

Humane exposure to RF signals for wireless power transmission may have severe health problems because continuous and frequent exposure to RF signals during the charging of implanted circuits leads to exciting body tissues. therefore, it is important to further investigate the non-ionization energy level of these signals used in implantable devices. It is also observed that the charge carriers in CNTFETs are having high mobility, due to which tissues will be getting excited. Therefore, we can further explore the health repercussion of the CNTFET-based implantable circuits working in an RF environment.

4. Conclusion

The ability to power biomedical implanted devices remotely has sparked the interest of industries and academia. This involves wirelessly power transfer techniques to power up wireless sensors, RF Identification (RFID) tag, and implantable devices, which are getting miniaturized with the device technology and face many challenges at the nanoscale dimension. Biomedical circuits at the nanoscale face many challenges like leakage current, sub-threshold power consumption and limited battery lifetime, etc. To address these problems, it is important to look at other alternatives. At the nanoscale, carbon nanotube field-effect transistors exhibit excellent carrier transport and thermal and electrical properties. Therefore, the performances of several CNFET-based biomedical circuits are analyzed in this work and found, CNFET based circuits are having improved performance in terms of operating voltage (0.5V) consumption and speed (953MHz) in the nanoscale regime.

It can also be further explored in two aspects namely wireless fidelity and humane health issues associated with the implanted CNTFET power converter circuits. The characteristics of an antenna are crucial in analyzing the power and voltage conversion efficiencies of a converter in wireless power transmission. As a result, the antenna properties may be used in future studies for analysis. Health repercussions of implanted CNFET-based circuits may also be explored as to its works in the radio frequency range with high carrier mobility.

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