OPTIMIZED LC-RESONANT OSCILLATOR FOR BODY SENSOR NODES USING FinFET

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Abstract: Several LC resonator architectures have been reported by the researcher in the past which employed the bulk CMOS technology for its design. In the proposed work of this paper, LC resonance based oscillator is designed using two cross coupled n-FinFET. This oscillator circuit is designed for ultra-low power application like body sensor nodes. Thus, dynamic threshold body biasing technique is used to reduce the threshold voltage of n-FinFET. This design is capable of generating two phase sinusoidal clocks having the peak to peak voltage of 169.59 mV and optimized frequency12.58 MHz using the very low harvested input voltage of 96mV.

***Index Terms* – Cross coupled n-FinFET, LC resonant oscillator, Energy harvester, Body sensor nodes, Ultra-low power application, Dynamic threshold body biasing technique.**

I. INTRODUCTION

In this decade, the development of VLSI field enhances the proliferation of body sensor nodes in biomedical domain. These body sensor nodes have significant role for remote area monitoring and logging of patient medical records [1]. As they have great potential, but their conventional design restricts their wide practice in this domain. One of the design challenge is its battery. It has limited operating life span; therefore, it need to be replaced. This replacement will increase its maintaining cost and effort with increase in numbers of body sensor nodes. Thus, investigation of alternative power sources for body sensor nodes is required.

In the meanwhile, the ambient energy sources have replaced the batteries in many ultra-low power applications. Most of the energy sources like thermal, RF source, piezoelectric etc. have shifted the attention of researchers towards the development of energy harvesting techniques [2]. However, the power generated from these sources is not sufficient for ultra-low power application. They generate less voltage, for example: thermoelectric generator having suitable size for body sensor nodes can generate nearly 100 mV output voltage for a small temperature gradient [3]. So, it is required to convert these low voltages to higher voltage. A charge pump based boost converter circuit fit appropriate for these type of operation but to start and generate a clock signal at low voltage for charge pump is a challenging task. Thus, designing of start-up circuit for boost converter used in body sensor nodes is a key issue addressed in this research paper.

In this work, a LC resonant oscillator is considered as a start-up circuit for boost converter design. Its design uses the cross coupled n-FinFET devices and dynamic threshold body biasing technique to start the boost converter at very low voltage nearly 96mV. It enhances its performance and make suitable for ultra-low power application. The organization of various sections of this paper is as follows: In section II, architecture of LC resonant cross coupled n-FinFET based oscillator is explained. This design is analyzed using general body biasing technique for n-FinFET nodes. In section-III, body biasing technique is explained for controlling the threshold voltage of the device. In section IV, proposed design for LC resonant cross coupled n-FinFET oscillator using dynamic threshold body biasing technique is discussed. In section V, results of the proposed design is discussed. Finally, the paper is concluded in section VI.

II. ARCHITECTURE OF LC RESONANT CROSS COUPLED N-FINFET BASED OSCILLATOR

In case of energy harvested application, input power source provides very low voltage. It makes difficult to use ring oscillator or some other general oscillator architecture because they don't perform well at these low voltages and have limited peak to peak voltage by V_{dd} input voltage [1]. To get sufficiently large amplitude oscillation, LC resonant cross coupled oscillator architecture is appropriate for this application [4, 5]. It provides the peak to peak amplitude of oscillation nearly double of the V_{dd} input voltage.

Conventional CMOS based LC cross coupled oscillator have the short channel effects (SCEs) and large power leakage as the channel length reduces. As technology is scaled down and reached in the regime of few tens of nanometer, SCEs degraded the performance of CMOS devices. They lose the gate controllability on the channel. Further, CMOS based architecture have leakage current and poor efficiency for subthreshold region of operation. Recently, FinFET devices appeared as alternate choices for CMOS devices in subthreshold region. Actually, FinFET (Fin Field Effect Transistor) is a 3D structured device with multi-gate to have more and more interaction with channel length. So, this device has more controllability on channel by the gate terminal and shows better results [6].

In this work, FinFET devices are opted for switches operation in LC resonant cross coupled oscillator architecture. Figure 1 shows the architecture of FinFET based LC oscillator using general body biasing technique. This architecture consists of two cross coupled n-FinFET devices which act as switches alternately. Therefore, this architecture is capable of generating two different sinusoidal oscillation having 180^{o} phase shift. These oscillations can be obtained at Out1 and Out2 terminal in the design. For simplicity, only Out2 terminal is connected to external load. Here, the n-finFETs NM0 and NM1 are working in weak inversion region due to low

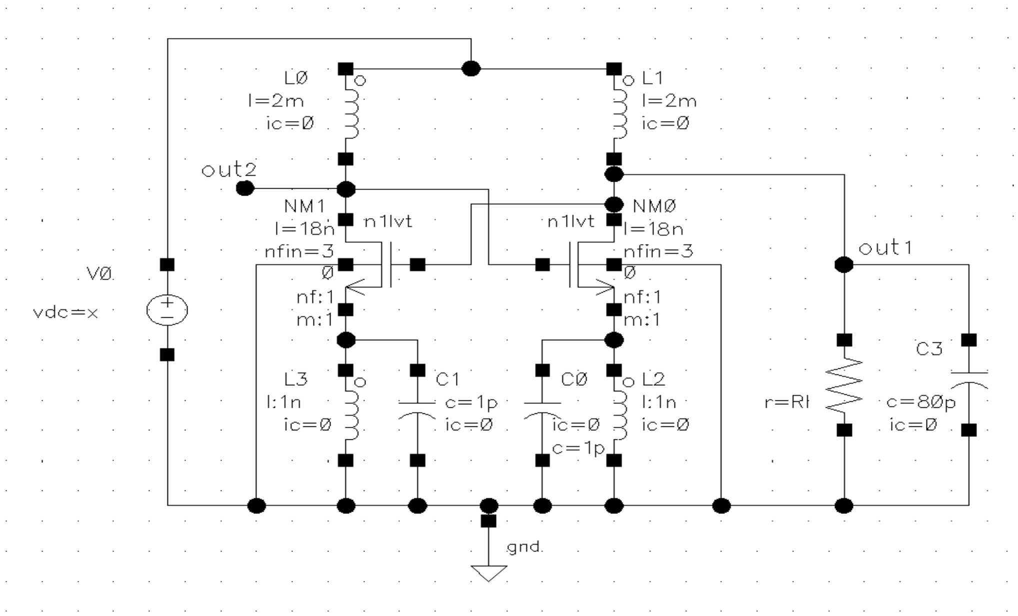

Fig.1: n-FinFET based LC oscillator using general body biasing technique

input voltage at the initial stage. Their body terminals are connected to GND which is a general body biasing practices in VLSI design. Firstly, any one n-FinFET starts conducting more as compare to other one due to the noise and parameter mismatch which brings other n-FinFET to OFF state. In second half, second n-FinFET comes in conducting state and first one in OFF state. This will generate oscillation through the resonant load of L1 and C3. Therefore, oscillation frequency depends upon these components as follow:

$$f_o = \frac{1}{2\pi\sqrt{L1.C3}} \qquad (1)$$

Further, component C0 and L2 are deciding factor for initial start-up voltage. This start voltage should reach voltage level achieved from the harvested power source.

III. Threshold Voltage Control Using Body Biasing Technique

Threshold voltage is an important parameter for switching application specially for ultra-low power circuits. Its value decides the switching characteristics of the circuits and finally overall performance of the design. For ultra-low power application, it is required to have low threshold voltage because input power source provides very low input voltage. If threshold voltage is high, it is not possible to perform switching operation in the device. Therefore, to reduce the threshold voltage, numerous processing methods in MOS fabrication are implemented. Although, body biasing technique is best option for circuit designer to have control over the threshold voltage of the device.

Generally, the body of n-FinFET is connected to GND terminal of the circuit as shown in figure 2. Therefore, body and source are at the same potential. As V_{sb} (Voltage across source and body) is not zero, body effect exists in the device. This body effect can be utilized here to control the threshold voltage of the device [7]. The equations for threshold voltage used for MOS devices are as follow:

$$V_t = V_{t0} + \gamma \left(\sqrt{\phi_s + V_{sb}} - \sqrt{\phi_s}\right) \qquad (2)$$

which can be linearized for small source or body voltages as:

$$V_t = V_{t0} + k_\gamma V_{sb} \qquad (3)$$

where $k_\gamma = \frac{\gamma}{2\sqrt{\phi_s}}$

V_{t0} is threshold voltage at $V_{sb} = 0$

V_{sb} is voltage across source and body

γ is body effect coefficient

ϕ_s is surface potential at threshold

Equation 3 describe that when source to body voltage is applied to the device, its threshold voltage varies [8]. If V_{sb} voltage across source and body is positive quantity, then threshold voltage increases, otherwise it is decreases for negative value of V_{sb} voltage. This phenomenon is also called as Body Effect. Thus, it can be realized for controlling of threshold voltage of n-FinFET device according to the application.

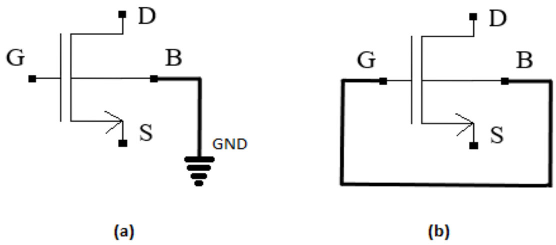

Fig. 2: n-FinFET device with (a) General body biasing technique (b) Dynamic threshold body biasing technique

IV. PROPOSED CROSS COUPLED FINFET BASED LC OSCILLATOR USING DYNAMIC THRESHOLD BODY BIASING TECHNIQUE

This proposed work suggested the dynamic threshold body biasing techniques to manage the threshold voltage. Here, the body and gate terminals of the device are connected to each other as shown in figure 2. Therefore, in-spite of having fixed biasing, body have dynamic biasing with respect to gate voltage. When V_{GS} is positive voltage in n-FinFET, it makes body terminal to forward biased with respect to source and in result, threshold voltage reduces. Thus, n-FinFET switching is shifted to lower applied voltage and derive the more current in the device. For the negative V_{GS} voltage, body is now reversed biased with respect to source terminal and increases the threshold voltage. Thus, power and current leakage reduces in OFF state of n-FinFET switch. Hence, this proposed technique is a substantial part of this work to lower down the operating voltage and leakage power of LC resonant oscillator.

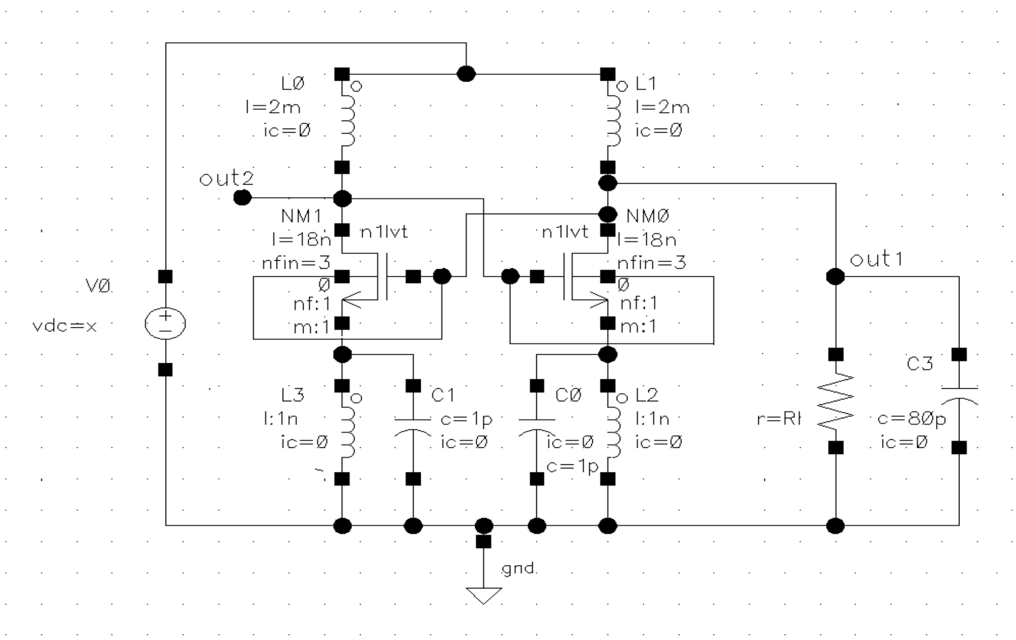

Fig 3: LC resonant cross coupled n-FinFET oscillator using dynamic threshold body biasing technique

The architecture of proposed LC resonant cross coupled n-FinFET using dynamic threshold body biasing technique is shown in figure 3. This dynamic body biasing technique creates two different threshold voltage for ON and OFF state of n-FinFET and its value depend upon body biasing through the gate voltage. This enhance the performance of proposed design. For better results, the values for circuit components are obtained by optimization and simulation on Cadence tool. The L0 and L1 are chosen to be off-chip component due to its large size.

V. RESULTS AND DISCUSSION

The proposed work is implemented with FinFET nodes from library: Generic (cds-ff-mpt) 0.8V/1.8V FinFET/Multi Patterned 8 metal Process Design Kit (PDK). These nodes are employed in 18nm FinFET technology. Figure 4 shows the oscillation generated from general body biased LC oscillator circuits. These oscillations have peak to peak amplitude nearly to 120.76 mV and 27.57 MHz frequency. In figure 5, output oscillation generated for LC cross coupled n-FinFET oscillator using dynamic threshold body biased is represented. The peak to peak amplitude and frequency of oscillation achieved in this work is 169.59 mV and 12.58 MHz respectively. These both simulations are carried out with 96mV input voltage source, 5 MΩ load resistance and same value of components for making a comparative study. These oscillations are captured at steady state of the circuit when frequency and amplitude becomes constant. These oscillations are generated for boost converter where they are used as clock signals for circuit.

Therefore, they are represented as clock signals in the figures. These results clearly evident that dynamic threshold biasing technique based architecture have achieved 40.44 % more peak to peak to amplitude and frequency is also optimized and reduced by 54.37 % in compare to general body biased based oscillator. In this architecture, frequency of oscillation and size of components are directly related to each other. As the L1 and C3 components are choose to have low value, it generates high frequency which leads to more switching power dissipation and if they have high value, it increases the size of component and in result, area of design. So, dynamic body biasing technique also helped in achieving less power loss with having same area of design as compare to general body biased circuit.

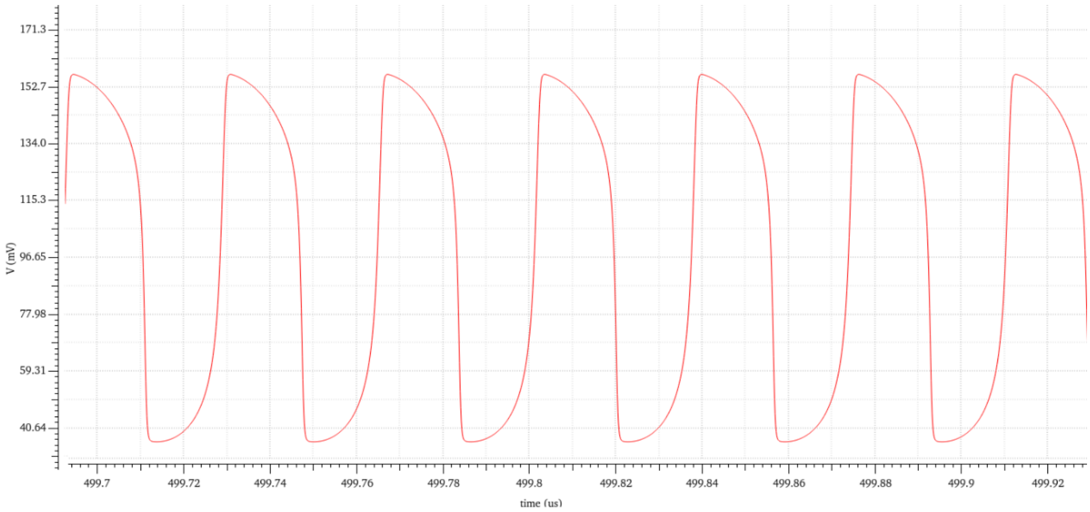

Fig. 4: Output oscillation with general body biasing technique

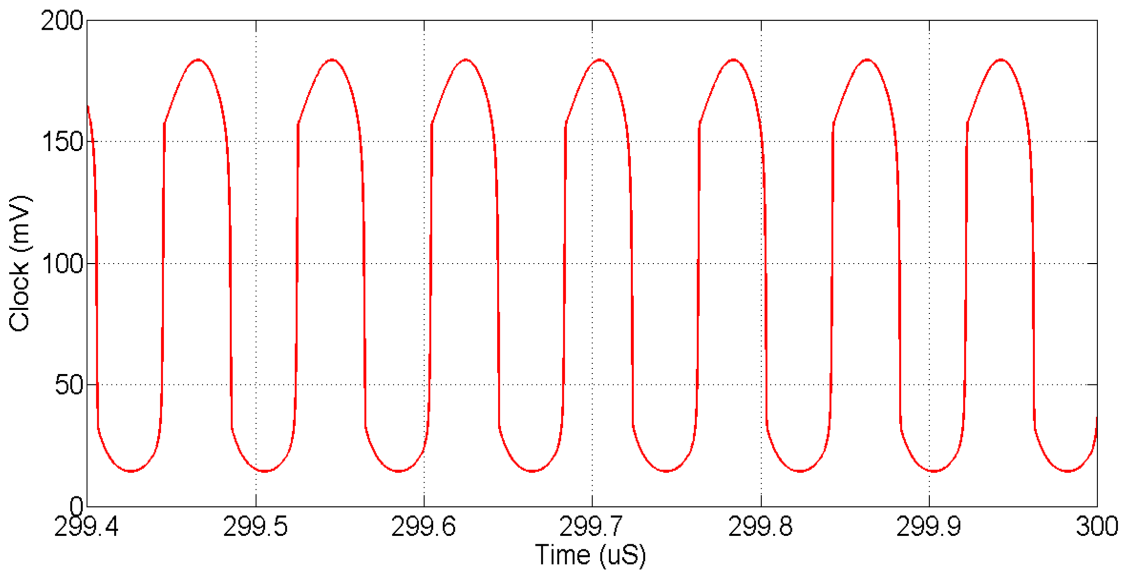

Fig. 5: Output oscillation with dynamic threshold body biasing technique

Figure 6 shows the clock amplitude and clock frequency variation with input source voltage at 5 MΩ load resistance. It can be analyzed here that clock peak to peak amplitude increases with increase in input source voltage. As input source voltage increase, it has two impact on the circuit operation. Firstly, more energy is stored in LC resonant circuit which boosts the amplitude of the clock. Secondly, gate voltage of the devices also increases, it enhances the body effect on the devices. So change in threshold voltage would be more for ON and OFF states of devices and in result, time duration for ON and OFF state would also increases. It would help in store more energy in resonant circuit and enhancing clock amplitude. Meanwhile, increase in time duration of ON and OFF states of devices, also decreases the frequency of clock signal. Same can be verified from the relationship of clock frequency and input source voltage shown in Figure 6. For 400 mV input voltage source, peak to peak amplitude and frequency achieved in the design are 777 mV and 2.80 MHz respectively.

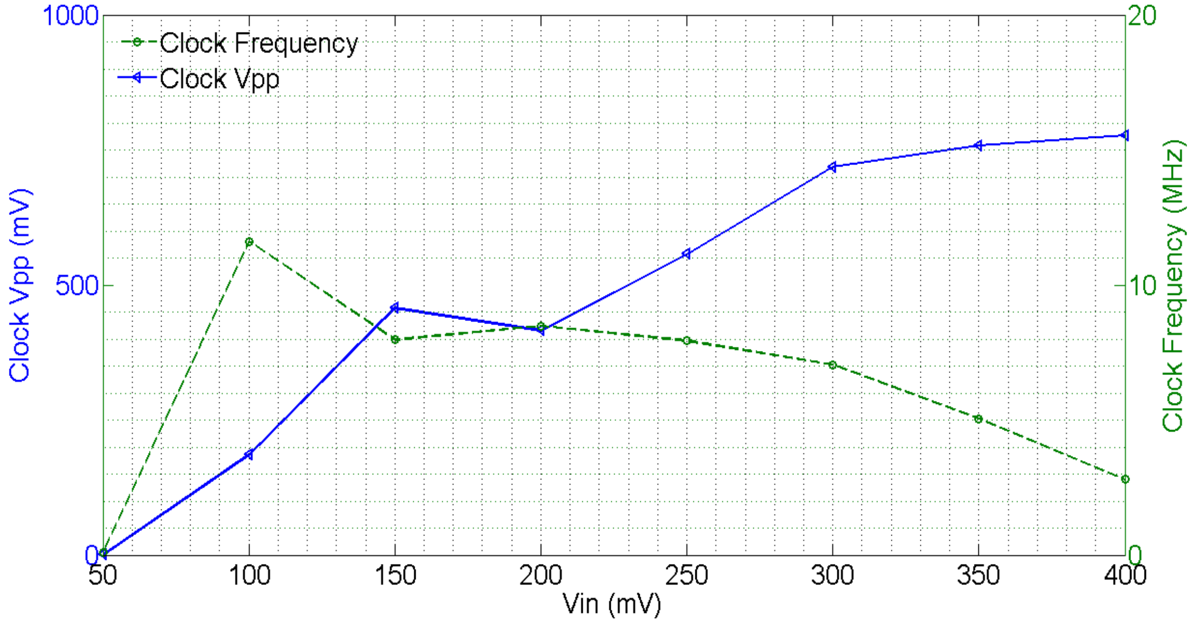

Fig. 6: Clock amplitude and clock frequency vs input source voltage

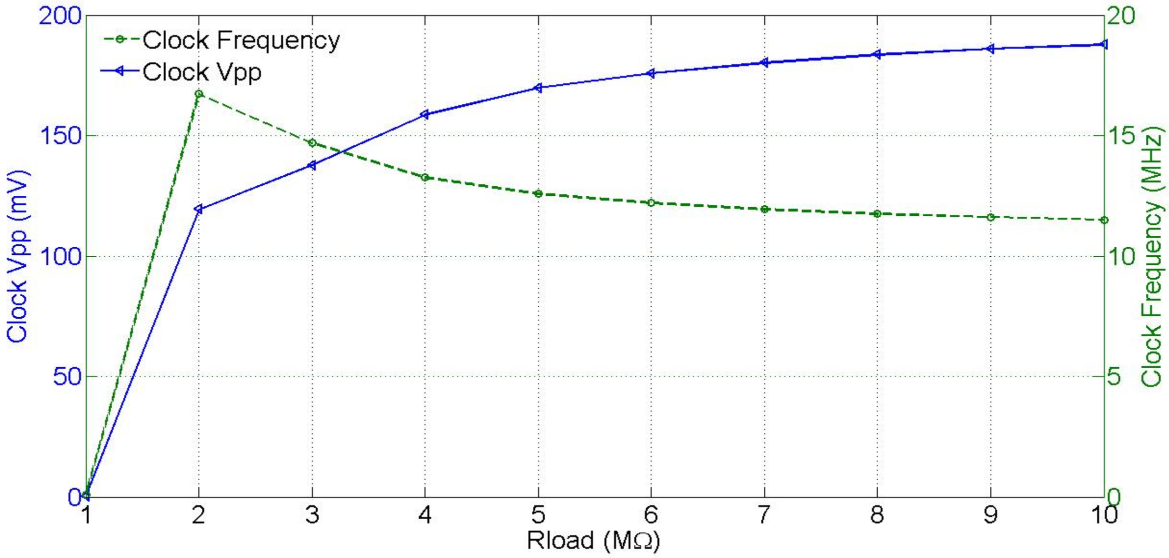

Fig. 7: Clock amplitude and clock frequency vs external load resistance

Figure 7 signify the relationship of clock peak to peak amplitude and clock frequency with external load resistance. It represents that clock amplitude increases with load resistance and clock frequency decreases with load resistance. As load resistance increases, better load matching take place and circuit shifts towards stable state. Therefore, these parameters get nearly constant values as load resistance increases. This design has 169.59 mV clock amplitude and 12.58 MHz clock frequency at 5 MΩ load resistance which varies to 187.64 mV and 11.50 MHz respectively at 10 MΩ load resistance. In table I, results of few related studies are compared with current research.

Table 1: Comparison of results with previous research

Ref.	Process	Technology	Input voltage	Output Clock voltage	Clock Frequency
[9]	180 nm	CMOS	300 mV	1 V	N.A.
[10]	180 nm	CMOS	140 mV	2.2 V	N.A.
This work with general body biasing technique	18 nm	FinFET	96 mV	120.76 mV	27.57 MHz
This work with dynamic threshold body biasing technique	18 nm	FinFET	96 mV	169.59 mV	12.58 MHz

VI. Conclusion

A LC resonant cross coupled n-FinFET oscillator has been presented using the dynamic threshold body biasing technique. This architecture is intended to use in ultra-low power application for starting the circuit and providing the clock for further operation. This design works on 96 mV input voltage and generate 169.59 mV peak to peak sinusoidal clock with 12.58 MHz frequency. This design is also capable of generating two clock signal with 180^0 phase difference. This dynamic threshold body biasing based design achieve 40.44 % and 54.37 % improvement in clock amplitude and clock frequency parameters respectively as compared to general body biasing technique.

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