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IR Energy Harvesting based on Hybrid Wing Suit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) for an Improved Rectenna Design

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Abstract: In this manuscript IR Energy Harvesting using hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) for Designing an Improved Rectenna. In this technique, to design the rectenna using the input AC current is taken from the IR rays and given to the rectenna (combination of antenna and diode) to get antenna coupling efficiency and diode(MIM) responsivity. In this some iteration will occur, to get optimal solutions and to increase the maximum coupling efficiency and responsivity here used an algorithm known as hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO). The experimental outcomes portrays that proposed system sandpiper shows the better performance such as the coupling efficiency7.39%, Responsivity 6.47%.Gives better performance than Genetic algorithms (GA), metal–insulator– insulator–metal (MIIM) diode optimization and Boolean optimization algorithm with triple port rectifier.

Keywords: IR Energy Harvesting, Wingsuit Flying Search Algorithm (WFSA), Chaos Game Optimisation (CGO). Metal-Insulator-Metal diode.

1. INTRODUCTION

Now a days harvesting energy from various resource is becoming a major issue in problem in day-by-day life. There is various resource to select energy harvesting process such as Infrared radiation energy harvesting [1,2], wireless sensor network[3,4], solar energy harvesting[5], among them Infrared radiation energy harvesting system [5,6] is used to construct the energy from earth or natural resource. In this infrared radius energy is harvested from earth and substitute for the various processes. In these discrete ways are taken to harvest and used renewable energy source [7, 8]. In this the harvested energy is converted to microwave frequencies to construct the rectenna [9, 10, 11]. The rectenna rectifies the high-frequency AC signal [12] as various electromagnetic radiations. To convert high frequency AC [13], signal a diode is used namely Metal – Insulator -Metal diode is place in between the antenna used to rectify the high frequency. Here nano antenna is implemented to get the good impedance matching with MIM diode [14] resistance. Due to the thin layer of the insulators may defect the diodes' non linearity and weaken its rectification ability. To solve the problems in the

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insulators a multiple insulator layers [15] are inserted this will improves the non-linearity problem. By inserting multiple layers of insulator into MIM diodes, their thickness will damage the equivalent capacitance of the diodes and determine the cut-off frequency. Here the objective function is not uniform and lots of stationary points are satisfied. In this to get more optimal solution here proposed a hybrid algorithm known as hybrid Wingsuit Flying Search Algorithm (WFSA) And Chaos Game Optimisation (CGO).

In this manuscript the objective is to harvest energy from the Infrared radius and give to the rectifying antenna which uses Metal insulator metal diode (for rectifying process). In this the input infrared radiations in this process the energy is taken from the earth and convert to microwave frequencies then given to diode the in-put current is ac current then convert to Dc current[16] by using rectenna. In this method the rectenna coupling efficiency and diode responsivity is optimized. To maximize the coupling efficiency MIM diode [17] is used and to take the product of coupling performance and response capacity is taken as the product. For obtaining more coupling performance and responsivity here proposed a hybrid algorithm known as Hybrid Wingsuit Flying Search Algorithm (WFSA) And Chaos Game Optimisation (CGO).

The major contributions of this manuscript are recapitulated below:

In this manuscript, IR Energy Harvesting using hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimization (CGO) for Designing an Improved Rectenna.

- In this manuscript, here to optimize the coupling efficiency and diodes responsivity [18] is maximized using proposed optimization algorithm WFSA and CGO.
- The energy harvesting applications needs an array, which may gather more incoming power and convert to effective DC current.
- Various antennas and their corresponding resonance wavelengths and bandwidths covering the frequency range of interest.
- Then Multi-Insulator – diode is utilized for proposing more freedom for their resistance and response capacity.
- Current-voltage features are calculated using quantum transmitting boundary method (QTBM) depends on airy functions. So, hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) is proposed for solving the optimization problem.
- Here hybrid Wingsuit Flying Search Algorithm (WFSA) [19] and Chaos Game Optimisation (CGO) [20] is integrated to gradient-based approach looking for best efficiency of rectenna is utilized.

2. LITERATURE SURVEY

In 2018, El-Araby et al. [21] has presented a geometric diode nano-antenna method for energy capture. Geometric graphene-based diodes were coupled to nano antennas for infrared (IR) energy harvesting technique. IR harvesting using nano antennas and the DC voltage composed from the nanoantenna were rectified using the geometrical diode its coupling efficiency was calculated.

In 2018, jeyaswal et al. [22] has presented a totally passive 28 THz zero-bias rectenna for energy harvesting from infrared (waste heat). Waste heat existing on mid-infrared (IR) range and taken as renewable energy source. In this, the mixture of a plasmonic antenna and high speed Metal / Insulator / Metal (MIM) diode, was used to form a rectenna and rectifies IR to produce useful DC.

In 2017, Tumendemberel et al. [23] has presented a bow tie nano-rectenna optimization topology for solar energy harvest applications. In this process, check the effects of the nano-antenna shape determine the performance of a whole structure of nano-rectenna for defined bow-tie geometry. The results validate that by accepting the bow tie topology, the radiation performance of aluminium dipole was maximized 51% to 61% and performance was 46% to 57%.

In 2017, shen et al. [24] presented a multiport pixel array for RF energy harvesting. Radio Frequency (RF) energy harvesting contains an optimal triple port pixel antenna and rectifier through DC combining. The multi-port pixel benefit includes improved harvested RF power. The triple port pixel antenna optimization was performed by sequential comprehensive Boolean optimization and produce DC power output.

In 2018, Rong et al. [25] has presented body-centered nano-networks driven by nano-rectenna in terahertz band. A body-centered wireless nano-network contains numerous nano-sized sensors with healthcare application. The contests on the network were produced with imperfect power and also stored in nano-batteries. Nano-rectenna broadband assets allow direct current (DC) electricity to be produced from THz inputs towards optical frequencies. Then compute the power output produced by the nano-rectenna shown in the THz band.

In 2020, Margeat et al. [26] have presented a rectifier antenna for the capture of energy from microwaves into visible light. It views the potential technical invention for energy harvesting. To improve the key point's sympathy to design rectifier antennas can form infrared and visible light, and the device manufacturing RF energy harvesting systems.

In 2019, Shilpil et al. [27] have presented a Rectifier of high potential frequency for metal-insulator-metal diodes (MIM) of Rectenna application. It rectifies the potential high speed frequency in rectenna based energy harvesting. The fabrication and characterization of graphene (Gr) -based Al / AlOx / Gr MIM diode were highly asymmetric current-

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voltage characteristics with high current density and better non-linearity degree. The results were given in highly potential in rectifying antenna efficiency.

In 2020, Ashim et al. [28] have introduced a Compact MIMO antenna with high port isolation for triple band applications intended with biomass material. The MIMO antenna substrate material description was thoroughly examined by analyzing their dielectric stable and loss tangent. The experimental results were performed for triple-band MIMO applications.

3. PROPOSED METHOD FOR DESIGNING IR ENERGY HARVESTING RECTENNA USING HWFSA-CGO

In this section designing IR energy harvesting rectenna using hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) is proposed to get more coupling efficiency and diode resistivity during Energy Harvesting process. Figure 1 portrays that architectural diagram of IR energy harvesting rectenna using Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO). In this method the input Infrared radiations (IR) are taken from the earth and produce input AC current, this current gives less efficiency and also noisy. Then this emitted is converted to microwave frequency and the frequency is calculated. Then the signals are sent to the rectenna to rectify the un wanted energies in the AC current. The rectenna consists of two elements such as Antenna and Diode. The Antenna works in the AC voltage source and the impedance with resistance and the reactance and the Metal-insulator-metal (MIM) diode is the combination of resistance and capacitance and it is connected parallel to each other for the rectification process. Then the current is converted into High Frequency AC current. In this process the efficiency is tackled due to the objective function such as, it is not smooth and many stationary points are existing. To optimize this problem an optimization algorithm is proposed such as a hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) and it will increase the total Antenna performance and diode responsivity. Then the output of rectenna is to get useful DC current for the Energy harvesting process.

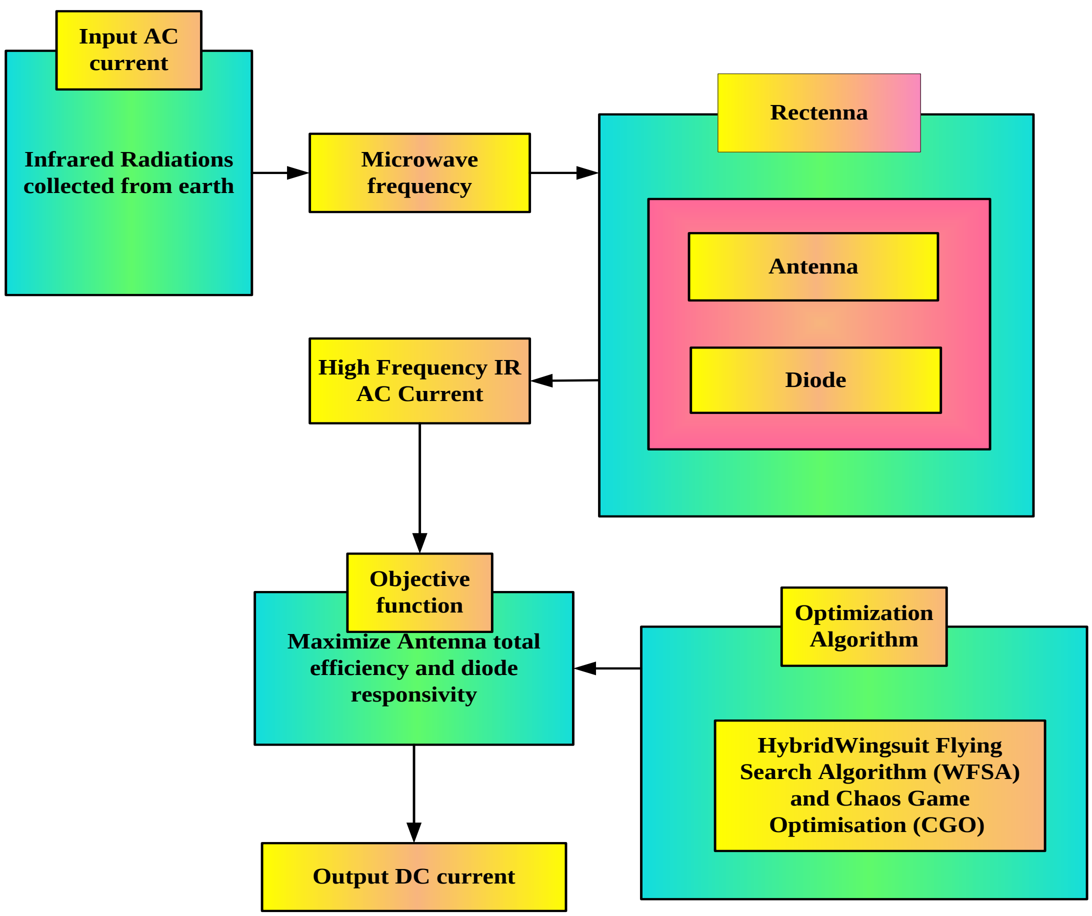

Figure 1: Block diagram for Rectenna

Rectenna is the combination of the Antenna and diode and it is used to rectify the unwanted frequency or signals in the antenna to get more efficiency in the Energy harvesting process. Then the antennas in the receiving section include and also designed in the ultrahigh-Frequency voltage source is shown below,

$$L_b = L\cos c(\nu r) \tag{1}$$

Where L denotes the voltage source, and connected at series with impedance of antenna B_z. Then the diode is modelled in parallel position with the combination of resistor and capacitor. To calculate coupling efficiency, it needs to combine both antenna and diode in one part. Then the coupling efficiency is given below;

$$\mu_k = \frac{O_f(powerdeliveredtoT_f)}{O_{inp}(antennainccidencepower)} = \frac{|L_f|^2/2T_f}{L_b^2/8T_b} \tag{2}$$

$$L_f = L_b \frac{f_z}{b_z + f_z} \tag{3}$$

$$f_z = \frac{T_f}{1 + i\nu K_f T_f} \tag{4}$$

Where resistance is denoted as L, Capacitance is denoted as K, impedance is Z, power is denoted as O, K_f and T_f is the resistor and capacitor and L_f is the voltage in all diode terminal. Then the Frequency is calculating as,

$$\nu = 2\pi f_1 \tag{5}$$

Then the equation 5 is known as device operating frequency. From equation 1 the efficiency is calculated as,

$$\mu_k = \frac{4\frac{T_b T_f}{(T_b + T_f)}}{1 + (\nu \frac{T_b T_f}{(T_b + T_f)} K_f)^2} \tag{6}$$

From equation 6 the numerator denotes the matching of impedance among antenna and diode. T_b is the range of few 10's and 100's ohms. For example, when implementing resistance $T_b = 100$, T_f become close to this value and increases the numerator. Then determine the equivalent resistor is,

$$T_{eq} = T_b T_f / (T_b T_f), \ (\nu T_{eq} K_f \ll 1 \tag{7}$$

The above equation 6 can clutch to catch maximum coupling efficiency.

Then the impedance matching state encourages using MIM diodes to get diode responsivity. This diode is holds low diode resistance, to get more resistance use ultrathin insulator layers. The MIM diode resistance is estimated by using the current voltage characteristics. By the process of insulating layer, the conduction of charges will be carried. So, the thickness of this layer is lower too few nanometres and the tunnelling probabilities will reduce gradually and to increase the insulator thickness.

The cut-off frequency is calculated for MIM diode coupled to the antenna for the performance of high frequency is given as,

$$d_{freq} = \frac{1}{2\pi TK} \tag{8}$$

Where T denotes resistance, K denotes capacitance.

The capacitance (K) is calculated as,

$$K = \frac{\varsigma_0 \varsigma_t B}{f} \tag{9}$$

ς_0 is permittivity in free space, ς_t denotes insulator material permittivity, B denotes active area, f denotes thickness of insulating layer of diode.

Then substitute the capacitance value in frequency in equation (8),

$$d_{freq} = \frac{1}{2\pi TK = \frac{\varsigma_0 \varsigma_t B}{f}} \tag{10}$$

In this resistance (T) is calculated by the inverse of the slope of current (u_i)voltage (L_v) curve and the resistance is more precisely dynamic resistance. Then the current with voltage is derived as,

$$T = \frac{L_v}{u_i} \tag{11}$$

$$T = \frac{dL_v}{du_i} - 1 \tag{12}$$

The asymmetry (μ_k) is the absolute relation of forward and reverse currents in certain bias voltage and then measure the diodes ability to perform rectification.

$$\mu_k = |\frac{1+}{1-}| \tag{13}$$

The non-linearity of the diode is used it sharpen or turn on the voltage and the double segregation of diode current regarding with voltage is given as,

$$\lambda = \frac{d^2 L_v}{du_i^{\,2}} \tag{14}$$

Then the responsivity of the diode, the DC output power and the ac input power can be calculated as,

$$\chi = \frac{1}{2}\left(\frac{\frac{d^2 L_v}{du_i^{\,2}}}{\frac{d\ L_v}{du_i}} \right) \tag{15}$$

Equation 6 shows the total antenna coupling efficiency and equation 15 is known as diode responsivity using the infrared radiations with energy harvesting. In this process the efficiency and responsivity are not approximate and some iteration are present, to avoid these iterations an approximation algorithm is proposed known as hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO).In this a hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) is proposed to rectify the coupling efficiency and the diode responsivity in the rectenna. Wingsuit hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) is the new optimization algorithm used to detect the earth surface to get infrared radiation emitted from the earth for the energy harvesting process and to convert input AC current to Output DC current. This optimization algorithm explains the behaviour, movements; of the IR radiations emitted least point of the earth with in the particular range. This algorithm is real-life easy to implement and lean procedure.

The efficiency of the optimization algorithm is determined as,

$$\mu_k = \begin{bmatrix} M_1 \\ M_1 \\ . \\ . \\ . \\ .M_x \\ . \\ . \\ M_v \end{bmatrix} = \begin{bmatrix} m_1^1 & m_1^2\ldots.. & m_1^x\ldots\ldots & m_1^f \\ m_2^1 & m_2^2\ldots.. & m_2^x\ldots.. & m_2^f \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ m_v^1 & m_v^2\ldots. & m_v^i\ldots. & m_v^f \end{bmatrix}, \begin{cases} x = 1,2,..v \\ i = 1,2,\ldots.f \end{cases} \tag{16}$$

Then the condition is changed to next position of the iteration of the dimensional grid to the neighbour selection.

Then the co efficient is calculated as,

$$V_0 = \left| \sqrt[v]{V} \right|, V \geq 2 \tag{17}$$

The equation 16, 17 shows the computational difficulty and convergence performance is calculated. Then hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) for enhance the real-life results. It will reduce the costs, and increase the reliabilities.

3.1 Step by Step procedure

In this section have to discuss thedesigning IR energy harvesting rectenna using hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) is proposed to get more coupling efficiency and diode resistivity during Energy Harvesting process. The proposed sandpiper optimization algorithm shows step by step procedure to designing the rectenna using IR rays input AC current is converted to output DC current and to maximize the coupling efficiency and responsivity is as follows:

Step 1: Initialization

Initialize the initial position V^* be the initial points and the population is given below,

$$V = V^* - 2 \tag{18}$$

Then the initial points are defined as,

$$\wedge i^{(1)} = \frac{i_{\max i} - i_{\min i}}{V_0} \tag{19}$$

Where $\wedge i^{(1)}$ is the maximum and minimum cost function

Step 2: Random generation

Then the random generation is estimated by the process of initialization step. Let f be the dimension and the random generation is given as,

$$m_j^j(0) = m_{j,\min i}^j + rando.(m_{j.\max i}^j), \begin{cases} j = 1,2\ldots.v \\ i = 1,2,\ldots.f \end{cases} \tag{20}$$

Where $m_j^j(0)$ provides the random generation in the initialization points, $m_{j,\min i}^j$ and $(m_{j.\max i}^j)$ is the maximization and minimization process with i^{th} and j^{th} values and the *rando* is the random number with intervals [0,1].

Step 3: Fitness Function

From the initialized values, a random number of solutions are created. Fitness function of solution is evaluated and the objective function is represented in an optimization of function μ_k in equation (6).

Step 4: Updation

Update the position using hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO)

In this step WFSA and CGO optimization algorithm assigns the designing of the rectenna and the best solution is generated by rearranging the equation 19,

$$m^{(x)} = (1 - b^{(x)} * \wedge m^{(1)} \quad (21)$$

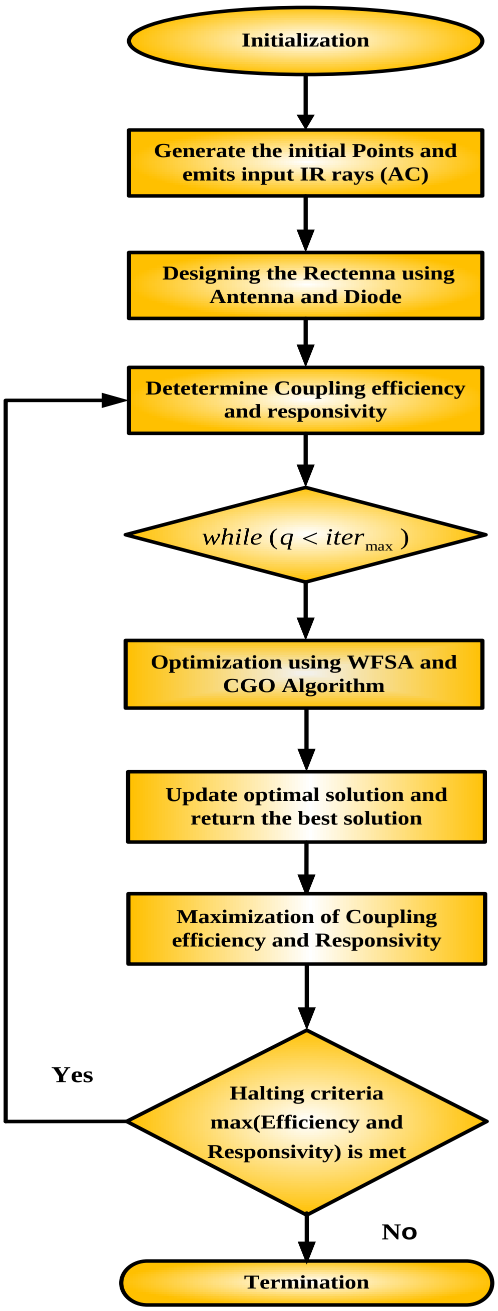

Figure 2: Flow chart for WFSA and CGO Algorithm

$$n \leftarrow M_j + g\tau M \quad (22)$$

From equation 15 the responsivity is calculated as,

$$\chi = \frac{1}{2}\left(\frac{\dfrac{d^2 \sum_{j=1}^{V^{(x)}+V} H(X).K^8(x)}{d^2 \sum_{j=1}^{V^{(x)}+V} .K^8(x)}}{\dfrac{d \sum_{j=1}^{V^{(x)}+V} H(X).K^8(x)}{d \sum_{j=1}^{V^{(x)}+V} .K^8(x)}_{v\ i}} \right) \quad (23)$$

Where $H(X)$ is the antenna responsivity function and the efficiency χ, $\tau M(\in IN - RAD)$ gives the step size objective function with the random variables with the infrared radiations in the earth.

Step 5: Maximization of coupling efficiency and responsivity

It is the metaheuristic algorithm and used in the optimization process to maximize the coupling efficiency and responsivity to design the antenna and to produce useful DC output.

From equation 22 the maximization process is formulated below,

$$d(n) < d(M_j) \rightarrow M_j := n \quad (23)$$

Where d is the objective function solution derived from the coupling efficiency and responsivity.

Step 6: Termination

The hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) optimizes the problems in rectenna design using antenna and diode to maximize the coupling efficiency and to increase the responsivity to get useful DC output using input AC infrared radiations (IR) for energy harvesting process.

4. RESULT AND DISCUSSION

In this section, the hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO) optimizes the problems in rectenna design using antenna and diode to maximize the coupling efficiency and to increase the responsivity to get useful DC output using input AC infrared radiations (IR) for energy harvesting process. In this the simulation performance of the proposed the MATLAB simulations are performed on PC through the

Intel Core is, 2.50 GHz CPU, 8GB RAM and Windows 8. Optimization algorithm starts with p_0 that are randomly selected by the hybrid WFSA and CGO. Here, equations with $\upsilon = 2\pi f_{req}$ and $f_{req} = 8.3$ THz matching towards wavelength 10.6 μm.

Table 1: Initial and Optimal Design Parameters

Parameters	**Initial**	**Optimal**
$Q1 = \Delta i_X$	-0.045 eV	0.041 eV
$Q2 = \Delta i_1$	0.55 eV	0.12 eV
$Q3 = \Delta i_2$	0.05 eV	0.17 eV
$Q4 = \varsigma_{T1}$	74	1.7
$Q5 = \varsigma_{T2}$	1.3	100
$Q6 = F1$	0.75nm	2.04 nm
$Q7 = f2$	3.5nm	1.20 nm
$Q8 = B$	$0.34 \times 0.36 \mu m^2$	$0.094 \times 0.088 \mu m^2$

From table 1, Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, $Q_7$and Q_8 are the design parameters. Δu_m and Δu_1 are the first two design parameter. f_1, f_2 is the thickness of insulator 1 and insulator 2, $\varsigma_{t_1}, \varsigma_{t_2}$ is the dielectric constants of each insulator, B is the area of diodes. The above table shows the optimal values of design parameters Q, also the zero-bias resistance value, coupling, and zero bias responsiveness. 7.39 A / W is the optimal zero-bias response value obtained, while 6.47% is the maximum coupling efficiency achieved. 3.90 kΩ is the zero bias resistance of optimal diode obtained that is not predicted since the predefined resistance of antenna is maintained 100 Ω.

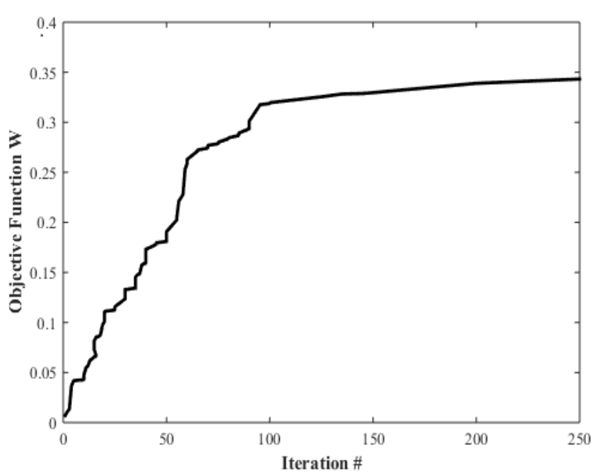

Figure 3: Convergence of WFSA and CGO

The algorithm joins the optimal parameter values demonstrated on Figure. 3. The zero-bias region permits self-switching operation. The optimal solution to this maximization issue is reached while the stopping conditions meet.

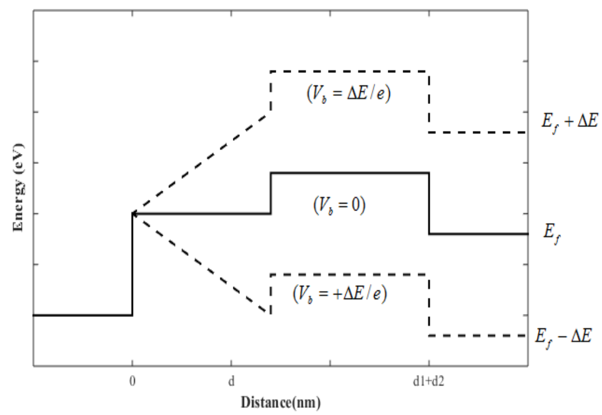

Figure 4: Optimal MIM design using zero-bias metal electrodes and tuned dc bias ±Δ*E*/e

Figure 4 represents the optimal design energy band diagram and gives the band diagram of wavelength 10.6 shaped on the incident IR radiation, photon energy 0.128 eV. The energy band and voltage principles are raised up 0.128 eV and down 0.128 eV. When comparing the forward and reverse bias curves are estimated that achieve maximum frequency on diode response. Energy bands at positively biased voltages allow electrons to pass during a triangular obstacle in minimum voltages.

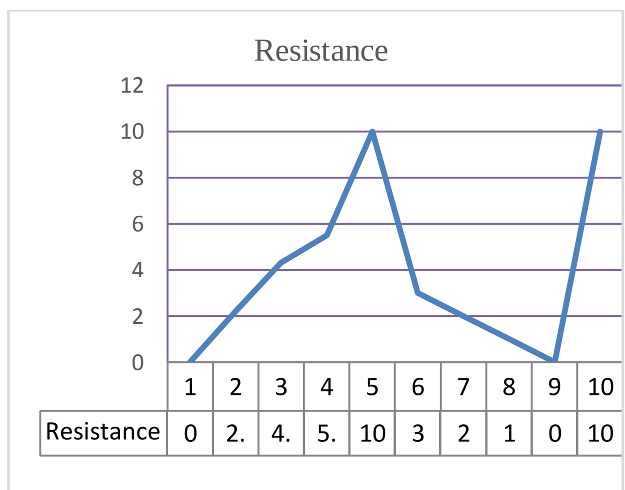

Figure 5: MIM diode resistivity

Figure 5 shows the diode resistivity and the resistance value, it gives more efficiency, and get the smooth derivatives and the diode resistance is calculated as resistance of 6.0 kΩ it is more than the MIIM – GAO method.

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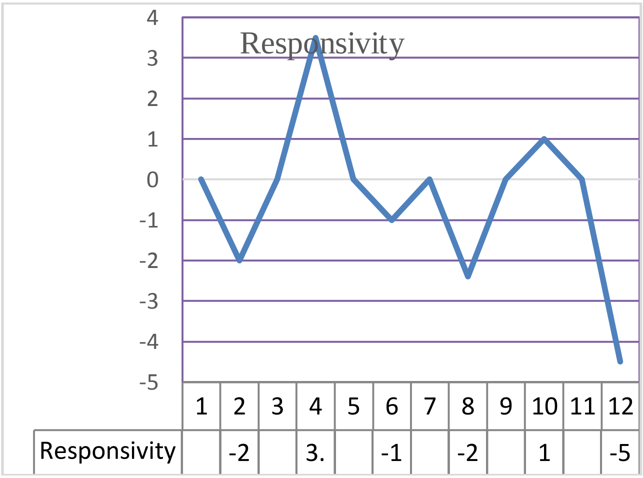

Figure 6: MIM diode Responsivity

Figure 6 shows the diode responsivity of the proposed MIM diode and the diodes maximum responsivity is calculated as 11.7 A/W at 160 mV, and zero-bias 1.8 A/W is more than the MIIM – GAO method.

5. CONCLUSION

In this paper, to design the rectenna using the input AC current is taken from the IR rays and given to the rectenna (combination of antenna and diode) to get antenna coupling efficiency and diode(MIM) responsivity. In this some iteration will occur, to get optimal solutions and to increase the maximum coupling efficiency and responsivity here used an algorithm known as hybrid Wingsuit Flying Search Algorithm (WFSA) and Chaos Game Optimisation (CGO). The experimental outcome demonstrates that the proposed system sandpiper shows the better performance such as the coupling efficiency7.39 A / W, Responsivity 6.47% gives better performance than GA, MIIM diode optimization and Boolean optimization algorithm with triple port rectifier respectively.

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