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Implementation Of A Low Power Silicon Beta Cell For Glucose Control In Diabetes

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Abstract **- This paper presents a bio-inspired blood glucose control method for diabetes based on a model of the silicon pancreatic beta cell.The analogue model of silicon beta cell is designed from the mathematical model of the beta cell. Normal blood glucose level limits from 70 to 140mg/dl. This model can be implemented using reduced number of samples (150 to 300mg/dl) which leads to reduced number of comparators in thermometer coder block. The proposed system is implemented block wise as in the existing system by using Tanner EDA tool and power consumption is calculated for each block and added together to calculate the total power consumption.**

Index Terms**:- Artificial Pancreas, Bio-inspired, Diabetes, Insulin delivery, Glucose control, Beta cell.**

I. INTRODUCTION

Diabetes Mellitus is one of the rapidly increasing disorders worldwide. Over 387 million people have diabetes as of 2014. This disorder is characterised by the increase of blood glucose level because of either the pancreatic beta cells are not producing enough amount of insulin(type1 diabetes) or the produced insulin is not functional(type2 diabetes). Insulin is a hormone that is secreted from our pancreatic beta cells. If the amount of insulin reduced then it will cause heart diseases, eye problems (retinopathy), kidney problems, stroke, nerve problems etc. To treat type1 diabetes the patient needs an insulin injection after their meals. Even though it is in practice the patients are not aware of the raising of blood glucose level putting then at risk (hyper glycaemia). So the control and complications trial [2] described the intensive insulin management reduced the patient's complications as much as 60-76%. This automated system leads to the development of artificial pancreas whose function is to replicate the function of biological pancreas to control the blood glucose level for the diabetes patients [3].

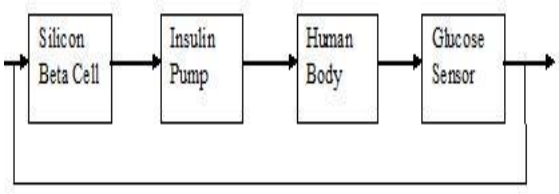


Fig 1: The Bio-inspired Blood Glucose Control using Silicon beta cell.

This artificial pancreas system includes:

1. An insulin pump that delivers insulin according to the level.
2. Glucose sensor that senses the blood glucose level.
3. A device having control algorithm to relate the rate of delivering insulin with blood glucose level.

There many kinds of insulin pumps [9][10] and rapid acting insulin alternatives [11]. Biostator was the oldest technology for artificial pancreas [4]. But it was only used in the clinic by the patient bedside. After few years the continuous glucose monitoring (CGM) [5] and insulin pump technologies had arrived in open loop fashion. Some glucose sensors and insulin pumps were described in [3][7].New promising solutions are emerging with minimal delay and faster control of blood glucose[8][12][13]. This paper organized as

follows. Section II describes the mathematical model of beta cell. Section III illustrates the analogue implementation and result analysis of each block. Section IV discusses about the results and the calculation of the total power consumption.

II. MATHEMATICAL MODEL OF BETA CELL

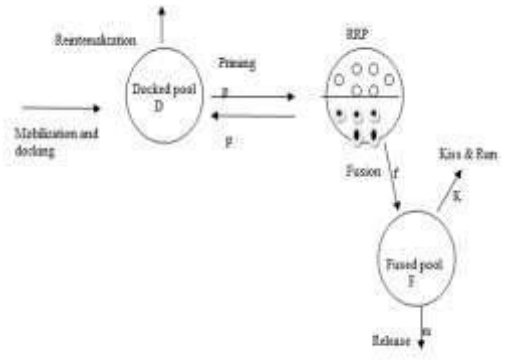
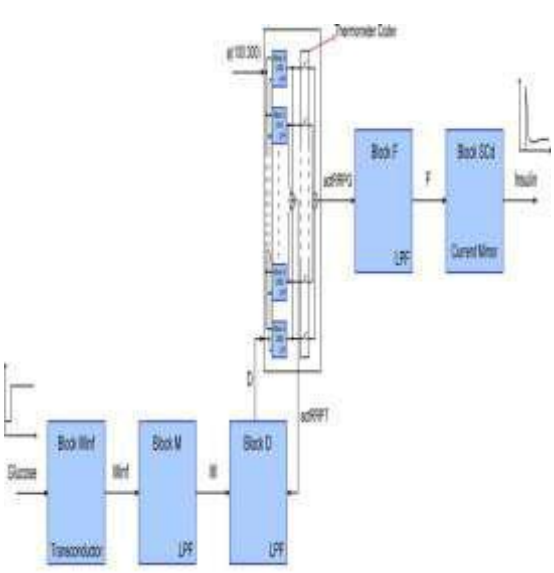


Fig 2. Overview of the beta cell model [22]. the RRP is divided into granules located in silent cells (white dot) and granules located into triggered cells(black dot).



The mathematical model of beta cell was first introduced by Steil and Colleagues [17]. In their model the accuracy was less than the beta cell model of Breda and Colleagues [18] for blood glucose control. More recent development of mathematical model of beta cell physiology, [19]-[22] leads to the development of a new class of bio-inspired glucose control algorithms Fig. 2 shows the overview of the beta cell model. In particular, the model introduces mobilization of secretary granules from a reserve pool to the cell periphery where they attach to the plasma membrane (i.e., *docking*) after *priming* cell entering the *readily releasable pool* (RRP). The possibility of so called *Kiss*

A. Transconductor block:

The basic function of transconductor is to convert the input voltage to current output. As discussed in equation (1) the value of G is the current value but the input is given as the voltage corresponding to the glucose value. The expression for the steady state mobilisation is explained by Hill equation [1]. And it is given by

(G)=————+ (2)

Fig 3: Block diagram of the system, the glucose input is given to the transconductor block and the signal passes through the circuit as current to block M,D,H, thermometer coder, LPF F and finally the value is multiplied by m to get the insulin output in current

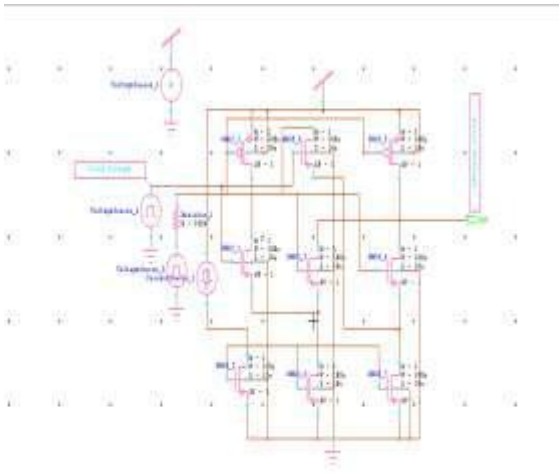


Fig 4: Schematic of transconductor block in Tanner EDA tool (version 13.0)

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To implement the function of equation (2) we need adders, multipliers and dividers. Due to its complexity a differential pair transconductor is used to implement the function as shown in fig 3.

B. Low pass filter block:

To implement the log domain filter the model needs Bernouli cell (BC) formalism [27] for the time dependent dynamics of the model [28].

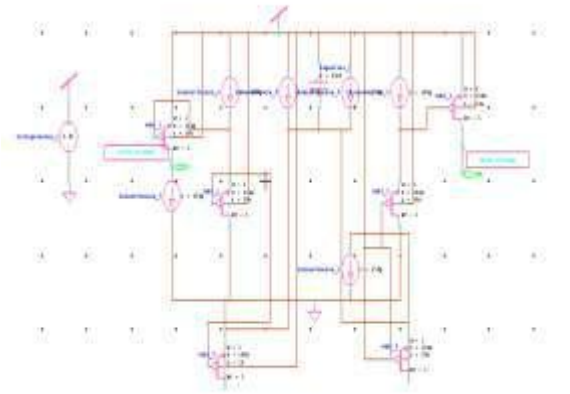

Fig 5: Tanner Schematic of LPF as proposed in [28]

Blocks	(A)	(A)	Capacitor(F)	(HZ)
M	100p	100p	45n	10m
D	380p	10n	300n	6m
F	1.76n	10n	48n	173.5m
h0	340p	100p	100n	15.9m
h1	20.8n	100p	100n	1

Table1: Parameter values for log domain filter as proposed in [1].

Fig 5 shows the circuit for LPF and Table I provides the required parameters. The values of *act RRPG* and *act RRPT* can be derived from [1]. And these two values can be given as the input to LPF blocks F and D. The values of currents were taken from [22]. All the LPF used were 1st order LPF with 20 db/decade attenuation. Table I summarized the values for current, capacitance and cu-off frequencies. All the currents have been chosen to be below 100nA to ensure that all the transistors are operates in weak-inversion mode.

C. Thermometer coder block:

As shown in fig 3 act RRPG and act RRPT is the inputs to the LPF block F and D from the thermometer coder block. Here act RRPG is the sum of all the output of h block whose glucose thresholds are higher than the input glucose value. If it is higher it closes the switch and process through the LPF F and multiplier circuit to generate the corresponding insulin value. Similarly act RRPT is the sum of all outputs from h block whose glucose thresholds are lower than the input glucose value. If it is lower the switch opens and the values again given as the input for LPF block D.

As discussed earlier the input glucose value ranges from 0 to 500mg/dl. So the system needs 500 comparators. But there is no possibility that a diabetes patient have glucose level less than
100. So it is enough to substitute 200 comparators and LPF (150:300).

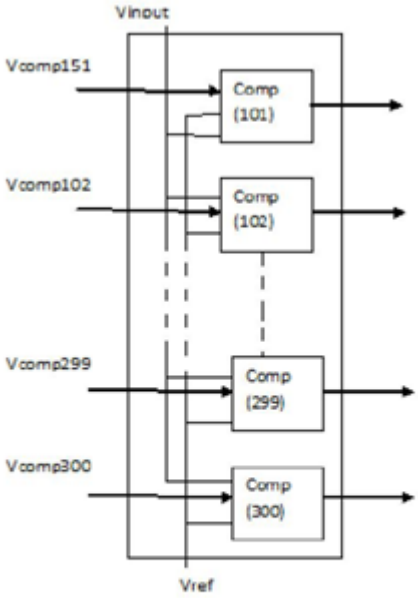

Fig 6: Thermometer coder block.

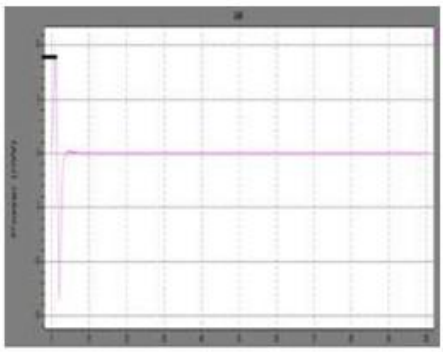

Fig 7: Power analysis for transconductor block (power vs time)

In the above figure the values Vcomp 151, Vcomp102,.....Vcomp300 represent the values of various threshold voltages for each comparator.

***D. Multiplier*:**

The multiplier circuit is used to compute the internal computations [1]. As discussed earlier from the mathematical model after fused pool the output current should be multiplied by the secretion constant m to get the final secretion rate.

$$SR(t) = m.\ F(t) \quad (3)$$

Here SR (t) is the secretion rate and m is the secretion constant. F(t) is the output of fused pool.

IV. RESULT ANALYSIS

A.Power analysis of trnasconductor:

The input voltage range is 100mV. The output current value is approximately 50mA. The schematic diagram is drawn in tanner EDA tool software. The transistor parameters are specified as (W/L=100µm/10µm). The main aim of this work is to reduce the total power consumption of the analogue model of beta cell. The first step is to find the power consumption of the transconductor bock. The input is about 100mV and the output is 50mA. The total power consumption of the transconductor block is 9nW. This reduction is achieved by the modified design of the transconductor block and the placement of the transistors.

C. *Power analysis of LPF block M:*

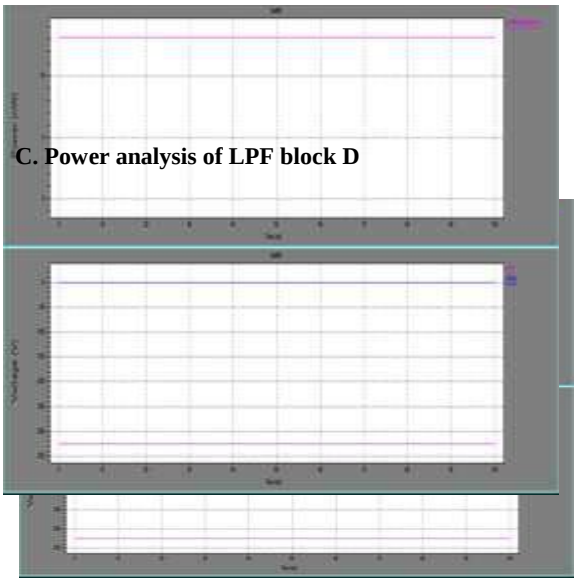

Fig 9: power analysis of LPF D (1.power vs time 2.Voltage vs time)

Fig 8: Power analysis of LPF M (1. Power vs time 2.Voltage vs time)

The output from the transconductor is given as the input for LPF M. The waveform shows the power consumption value of the low pass filter block M. The power consumption is about 6.4nW.

Multiplier	42.9nW	42.6 nW

The power consumption of LPF D is shown in figure 9. The power consumption is approximately 13.01 nw.

D. Power analysis of LPF block F:

The power consumption of LPF block F is given in figure 9. The power value is 2.3nW. Some power dissipation is occurred due to leakage power dissipation.

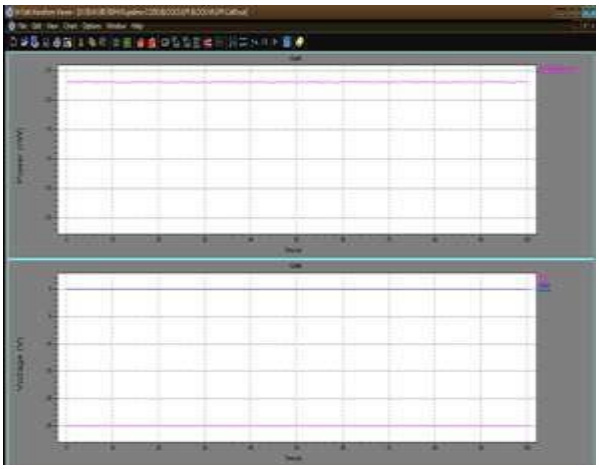

Fig 10: power analysis of LPF F (1.power vs time 2.voltage vs power).

D. Comparison table:

Blocks	Power consumption of existing method	Power consumptionof proposed method
transconductor	17.025Nw	9.5 nW
Block M	6.78 nW	6.4 nW
Block D	13.3 nW	13.01 nW
Block F	2 nW	2.3 nW
Block h	20 nW	19.8 nW
Comparator	9.35µW	9.2µW
Thermometer	1.85mW	1.84mW

V. CONCLUSION

A bio-inspired blood glucose control method for diabetes based on a analogue model of the silicon pancreatic beta cell is presented. The analogue model of the silicon beta cell is derived from the mathematical model of the silicon beta cell. The proposed system has very low power consumption. Instead of log domain low pass filter the Gm-C filter can be used to reduce the power consumption further. In addition the Gm-c filter uses on chip capacitors. This is the future implementation of this paper.

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