UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Design for Information Gathering with Mixed Protocols

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Ingeniería Electrónica y Automatización

Trabajo de fin de carrera presentado como requisito para la obtención del título de
Ingeniero en Electrónica

Quito, 23 de enero de 2023

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HOJA DE CALIFICACIÓN DE TRABAJO DE FIN DE CARRERA

Design for Information Gathering with Mixed Protocols

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Quito, 23 de enero de 2023

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RESUMEN

La diabetes en la actualidad se ha vuelto una enfermedad más recurrente, debido a esto a lo largo de este documento se revisará una forma de interacción con dispositivos enfocados en el control de esta enfermedad. Para esto nos valdremos de herramientas de síntesis como Vivado las cuales nos permite sintetizar sistemas digitales. De igual manera se partirá desde un diseño básico hasta uno mas complejo el cual incorpora herramienta y dispositivos mas avanzados. En la actualidad la tendencia al uso de microprocesadores se encuentra en aumento y es por eso por lo que se busca mediante este documento considerar la utilidad de los mismo.

Un factor que complica la vida de los pacientes que padecen diabetes suele ser el económico. Debido a que en la actualidad existen múltiples dispositivos los cuales tienen tiempos de funcionamiento limitado nos centraremos en una forma en aumentar la eficiencia del consumo energético.

ABSTRACT

Diabetes has now become a more recurrent disease, because of this throughout this document a form of interaction with devices focused on the control of this disease will be reviewed. For this we will use synthesis tools such as Vivado which allows us to synthesize digital systems. In the same way it will start from a basic design to a more complex one which incorporates more advanced tools and devices. At present the trend to the use of microprocessors is increasing and that is why it is sought through this document to consider the usefulness of them. A complicating factor in the lives of patients suffering from diabetes is often economic. Because there are currently multiple devices which have limited operating times, we will focus on one way to increase energy efficiency.

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INTRODUCTION

At present, a growing trend in the increase in diabetes can be evidenced. Having an increase of 391% from 1980 to 2014. Also presenting an increasing mortality rate of 3% between 2000 and 2019. There are two types of diabetes. Type 1 diabetes is caused by a genetic problem while type 2 diabetes is caused by poor sports and eating habits. [1] Throughout this document we will focus on type 1 diabetes since it requires treatment methods such as glucose sensors, electromedical infusion devices, glucometers, etc. [2] [3].

The treatment of this disease is around $ 2000 per month between insulin, lancets, sensors. [2] It is important to consider that this cost does not consider the value of an infusion device that is around prices between $ 6000 to $ 10,000 in the Ecuadorian market. [3] One issue that will be addressed in this document is the efficiency of treatment devices. Currently an electromedical infusion device must be used with AAA batteries which generates a great impact on the environment. Subdermal glucose sensors boast an efficiency of around 6 to 15 days. The protocols that are commonly used to transmit the information from these sensors are NFC the same that requires a device with the ability to read the data. [4].

This data extraction process can be annoying for the patient since it must be done in periods of 5 minutes in the best case. On this way, this document proposes a device with the ability to extract glucose sensor information with NFC and send it with Bluetooth.

The following document will have the following sections: Materials where we will review the circuits and tools used, Experimentation you can review in detail the steps that were followed for the design of the proposed device, results we will visualize the efficiency times obtained as well as the power consumption and Conclusions where we can have the applications and work in the future.

DEVELOPMENT

I. MATERIALS

A. BM019

The module is designed to work with the NFC communication protocol. This chip has an operation of 3.3 V and a current of 7 mA resulting in a power consumption of 23.1 mW. The device is manufactured by ST-microelectronics and is implemented to work in the frequency range of 13.56 MHz. This device also has compatibility for SPI and UART protocols. Additionally, the main operating module is the CR95HF integrated circuit, this device has the ability to work with signals in the range of 8 bits to 64 bits. [4], [5].

B. ESP32

The chip is focused on working with WIFI and Bluetooth protocols. This module has internally the Xtensa microprocessor which has 4 SPI port and 520kB for its SRAM. The device is focused on working with digital systems such as Arduino or Raspberry Pi. The electrical characteristics of the chip are the following 3.6 V at 80 mA and additionally requires that the source has the capacity to supply 500 mA for proper operation. [6].

C. CC2541

The device is focused on low-power work for the Bluetooth protocol. Its physical voltage characteristics are around 0.3 to 3.9 V. An important feature is that this integrated circuit has multiple modes of operation having its current ranges between 200 µA to 19.4 mA. With these electronics characteristics we obtain an average voltage and current of 1.8 V and 9.1 mA with a power consumption of 16.4 mW. One of the most important features is that it has an Intel 8051 processor which is focused on low consumption. It is important to note that the device in turn has the SPI protocol for communication between modules. [7]

D. Vivado

It is a software focused on the management of languages for HDL such as System Verilog. In this tool you can obtain the synthesis and implementation of digital circuits. This tool was used for estimating power consumption. It has compatibility with FPGA which allows us to have a real-time approximation to the operation of the device described. [8]

E. Nexys A7

It is a hardware focused on the synthesis and implementation of circuits made in HDL. It has the Artix-7 programmable matrix focused on the development of digital systems. This technology was developed by Xillinx which is a sub-company of AMD and which also developed the Vivado software. [8], [9].

F. Ibex

This processor is under development by RISC in its lowRisc division. An important note is that devices such as PIC have RISC technology in their processor. [ref] It is a processor with a 32-bit architecture. One of its main features is that this processor is focused on having a low power consumption. This unit has 2 main stages which are Instruction Fetch and Instruction Decode. In its electrical characteristics, it stands out that the dynamic power is 9 mW. [10]

G. FreeStyle Libre 2

It is a sub-dermal sensor focused on glucose monitoring. The main feature of this device is that it lasts for around 15 days with periodic measurements every 5 minutes. Its main communication interface is its NFC antenna which allows to extract the stored information. A physical limitation of this device is that it can store information for 8 hours. [4]

H. Lipo battery

A battery with the following physical characteristics 3.7V 100 mAh 28x12x5 mm was used. The main objective is that with a single charge of this battery it is possible to reach the 15 days of operation established by the glucose sensor. This battery has a controller which protects the device from overcurrent.

I. ISO 15693

It is a standard focused on reading “vicinity cards” which operate on the frequency of 13.56 MHz. In this standard you can obtain the base configurations to establish communication between devices with this technology. This standard is fully applicable in the NFC communication protocol.

II. EXPERIMENTATION

A. First Approach

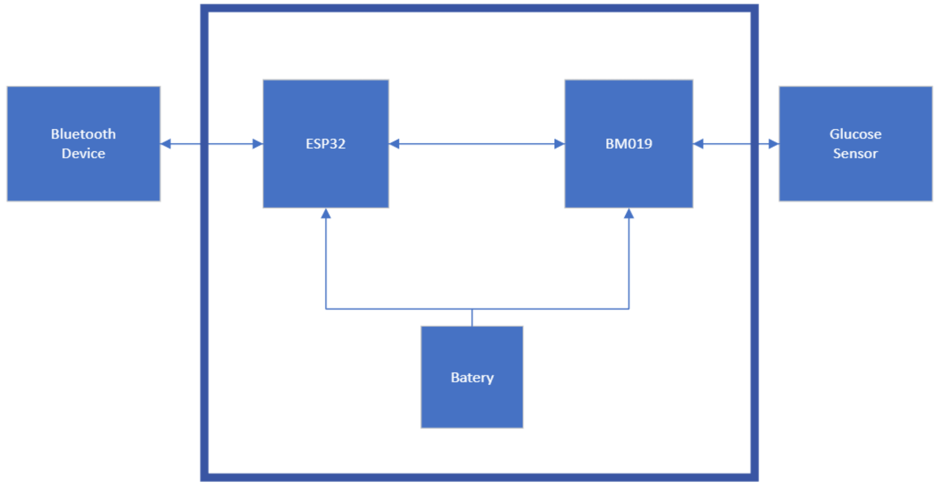

Fig. 1: Initial Electronic Diagram

At first, the operation with the ESP32 and BM019 modules was proposed since they comply with NFC and Bluetooth protocols. The design with all the modules used for the device can be seen in the Fig. 1. This generated a problem since the power consumed by the modules was high with respect to the capacity that can be stored in the Lipo battery as can be seen in the Table I. With the use of the described modules, an efficiency of around 1.48 continuous days was achieved. In this version the main unit of information processing is the ESP32 module. The ISO 15693 standard tells us the methodology of how to extract the information Byte by Byte For this first version of the device a physical sample was made as can be seen in the Fig. 2 which allowed us to check the operation of the design.

Thanks to the physical device it was possible to determine that without a continuous source the ESP 32 module fails after an operating time due to its physical characteristics. If a comparison is made of the power consumption established in the Table I and the power that the battery can supply over an hour, we obtain the Fig. 3.

Based on the graph we can determine that the replacement of the ESP32 module is of utmost importance since its power consumption is very high.

Device	Power
BM019	023.1 mW
ESP32	288.0 mW
Ptotal	311.1 mW
LIPO Baterry	370.0 mW

TABLE I: Instant power consumption

B. Increased up-time

Once a correct connection with the sub-dermal sensor could be established, it was sought to increase the efficiency of the device. As could be identified in the first version of our device the module with the highest consumption was the ESP32. To solve the problem of power consumption, 2 solutions are proposed.

1) First solution: In the first solution, the change of the ESP32 module for the System on Chip SoC CC2541 is proposed. The largest difference that can be identified between these modules can be visualized in the TABLE II.

Device/Data	Current	Voltage
CC2541	9.1 mA	1.8 V
ESP32	80 mA	3.6 V

TABLE II: ESP32 and CC2541 Comparison

If a direct comparison is made between the consumption by modules and the amount of energy consumed in an hour, we obtain the Fig. 4.

Fig. 2: Device image

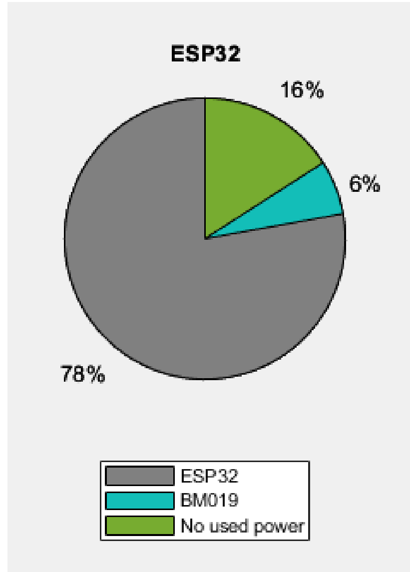

Fig. 3:Pie diagram of Power Consumption

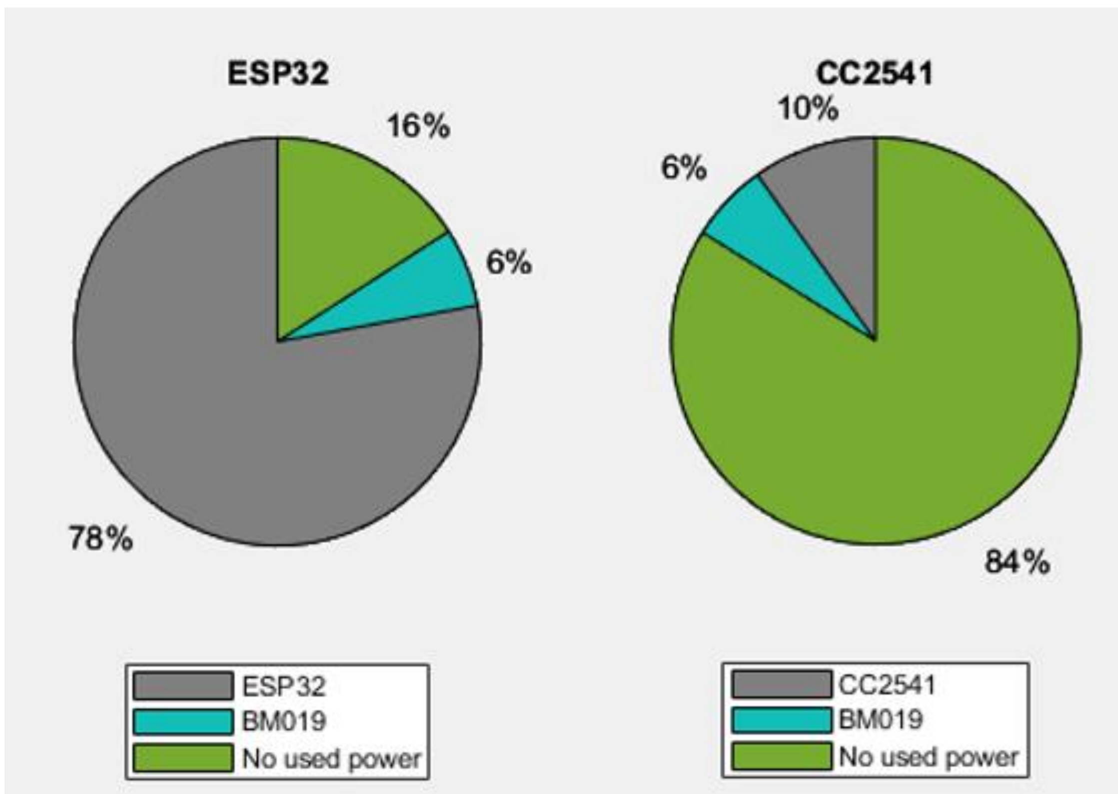

Fig. 4: CC2541 vs. ESP 32

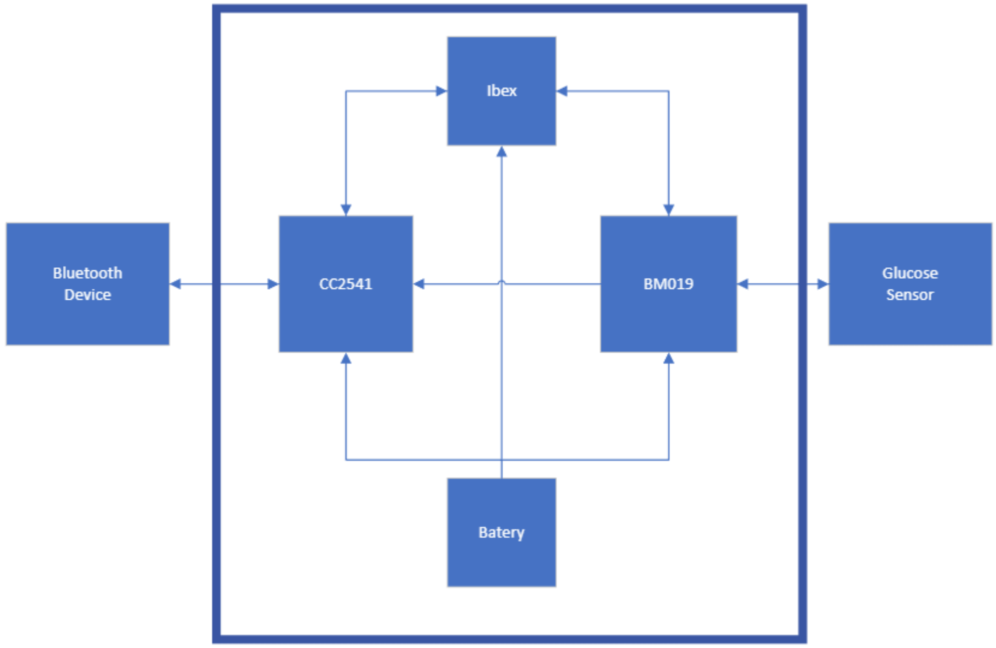

Fig. 5: Basic design with BM019 and CC2541

Also, in the schematic we obtain the Fig. 5 in which we can see the basic connection diagram between these modules.

2) Second solution: In order to increase operating times, it is proposed to work with a microprocessor such as Ibex. Working with the microprocessor helps us to have control over the decoupling circuits to increase efficiency [ref batteries and supercapacitors]. The Ibex processor is a project developed by RISC-V. This is an answer to be able to have a free use microprocessor. Because this microprocessor is in the development stage, it was decided to perform a synthesis of it in the Vivado software.

3) Ibex implementation: First to be able to carry out the implementation of the microprocessor it is necessary to understand all its stages which are: Instruction fetch, Instruction decode, Execute Block, Control and Status Register Block and Load-Store Unit. Once all the modules correctly declared and parameterized can obtain the RTL corresponding to the Fig. 6.

The microprocessor has the RegFile module which has three possibilities depending on the technology you want to use being these: FPGA, Flip Flop and Latch. Because we wanted to implement this module in the Nexys A7 device, FPGA was selected. [10] It is important to clarify that for the proper operation of the microprocessor a Dual port RAM is required. In order to perform the testbench, one was designed in System Verilog as can be seen in Fig. 7. Also, in order to verify that.

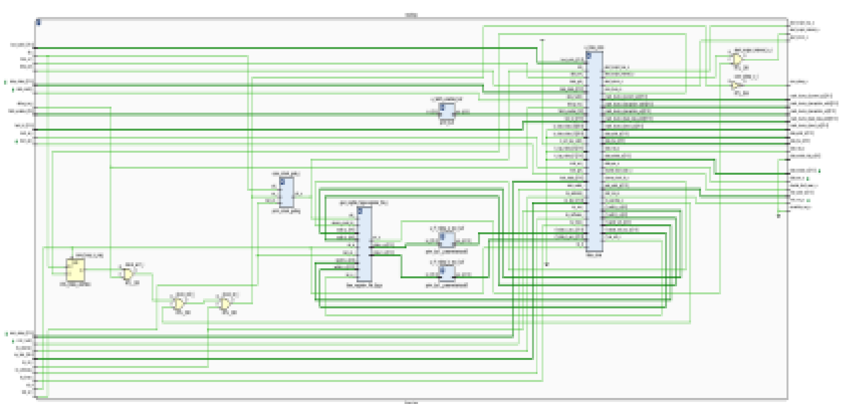

Fig. 6: Ibex RTL

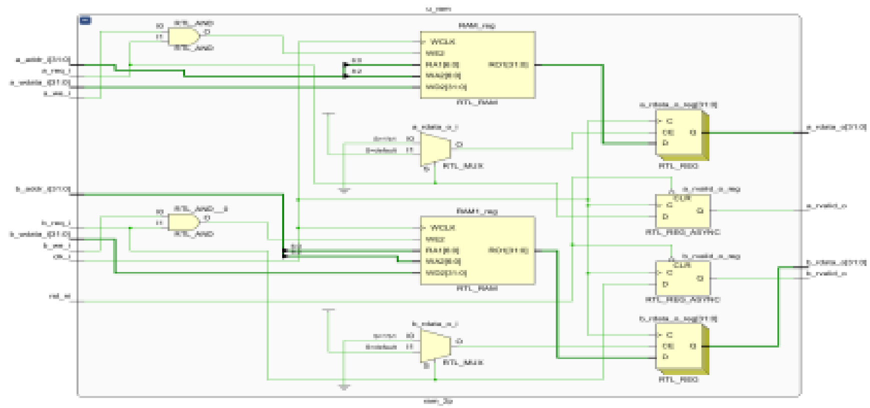

Fig. 7: Dual RAM RTL

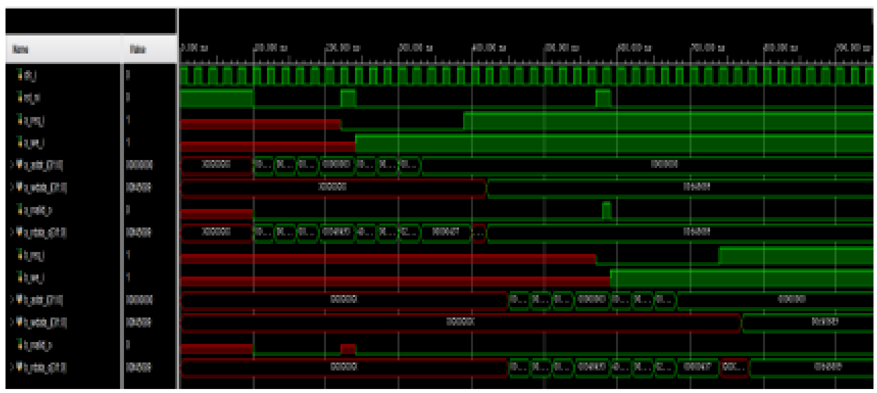

Fig. 8: Dual RAM Testbench

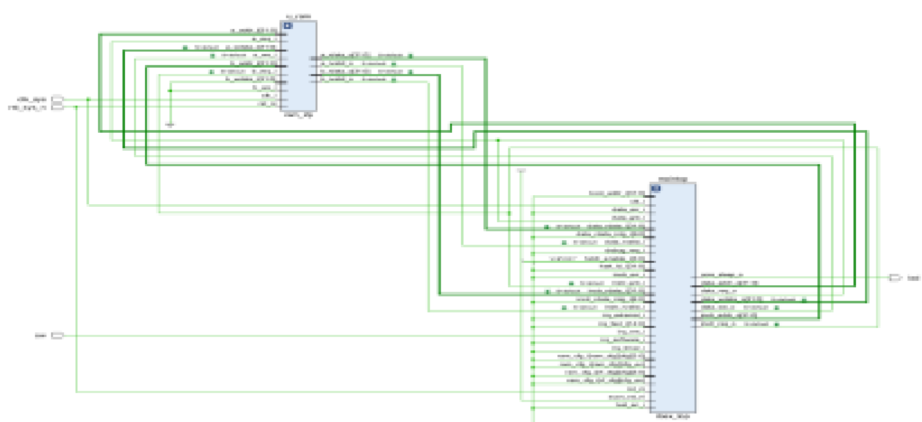

Fig. 9: Top RTL

this module is working, its respective testbench was carried out which can be visualized in the Fig. 8

it was possible to obtain the integration of the two modules in the same RTL as can be seen in Fig. 9. The implementation was carried out in order to obtain the dynamic power that our complete microprocessor would consume as can be seen in Fig. 10.

Once the correct implementation could be made, the bitstream was generated for the configuration of our FPGA where the correct operation of our microprocessor could be visualized.

```python
elif(instruction[0] == 'and'):
    rd = instruction[1].strip(',')
    rs1 = instruction[2].strip(',')
    rs2 = instruction[3]
    funct3 = '111'
    funct7 = '0000000'
    opcode = '0110011'
    mem_line = funct7 + registers[rs2] + registers[rs1] + funct3 + registers[rd] + opcode
    PC_cnt = write_to_file(mem_line, PC_cnt)
```

Fig.10: Python code

4) Calculation of instructions for the microprocessor: Because Ibex is a processor under development based on the architecture developed by RISC, the manual instruction set was used to develop a calculator which allows us to use assembly code for programming. In the Table III we can visualize the distributions of the bits for a 32-bit operation.

31-25	24-20	19-15	14-12	11-7	6-0
funct7	rs2	rs1	funct3	rd	opcode
0000000	rs2	rs1	111	rd	0110011

TABLE III: Ibex Instruction Set for AND

to this, a Python code was developed to be able to perform the transformation to hexadecimal as can be seen in the Fig. 11. This is necessary to be able to load the processor instructions which allow us to perform operations with the rest of the modules that are in the device.

III. RESULTS

In this section we will analyze the power consumption with the BM019, CC2541 and Ibex modules. This will allow us to visualize in an adequate way the amount of power consumed from our source.

A. Power Optimization

It is important to identify that in the first version of our devices we had an efficiency of 1.48 days of operation. In this analysis we will have 3 versions: V1 device with ESP32, V2 device with CC2541, V3 Device with Ibex. As can be seen in Fig. 12 we have a jump in efficiency from 15.9189% to 87.8%

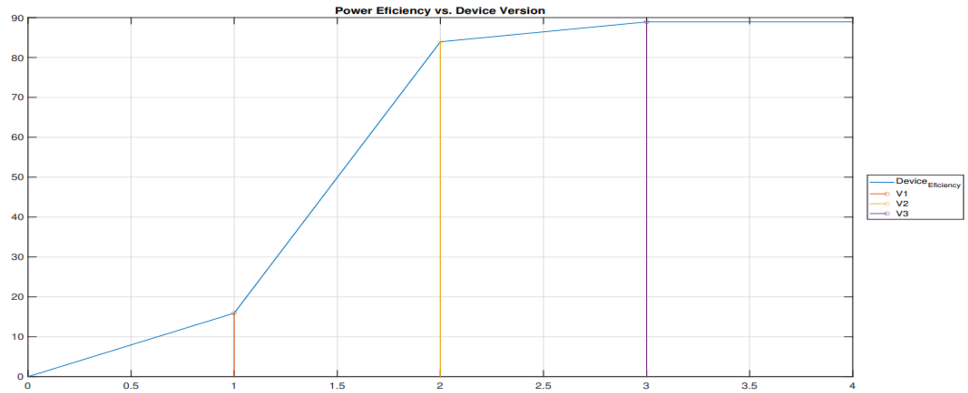

Fig.11: Power Efficiency vs. Device Version

B. Operating days

Likewise, the Figure 12 demonstrate that there is a considerable increase in the days of operation from 1.48 days to 8.16 days. This feature is important since the device is focused on monitoring patients with diabetes. Having an operating time of 8.16 days allows us to have a very detailed control over the patient.

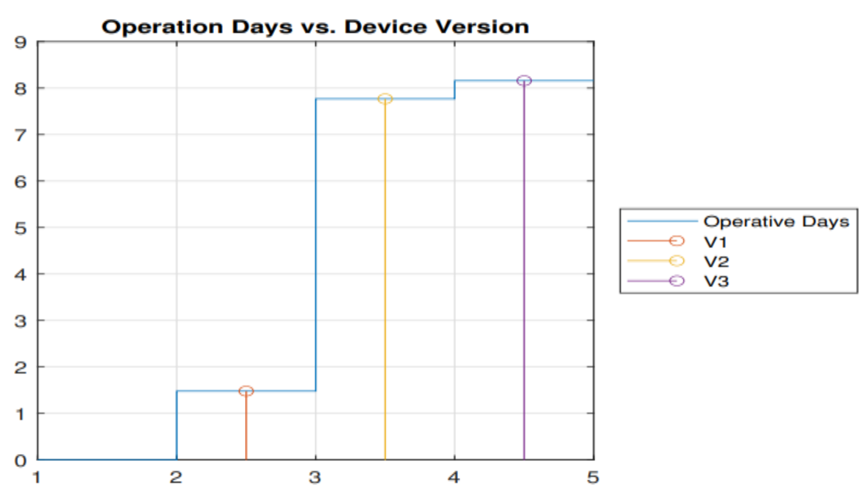

Fig. 12: Operation Days vs. Device Version

As can be seen in Fig. 13, a dynamic power of 9 mW was obtained, which indicates that the microprocessor is working at low consumption. This consumption benefits us because one of the main objectives is to increase the efficiency time. Additionally it can be displayed in the static range that we have a consumption of 62 mW. It is important to understand that dynamic power depends on the technology being used and can be modified in the manufacturing process.

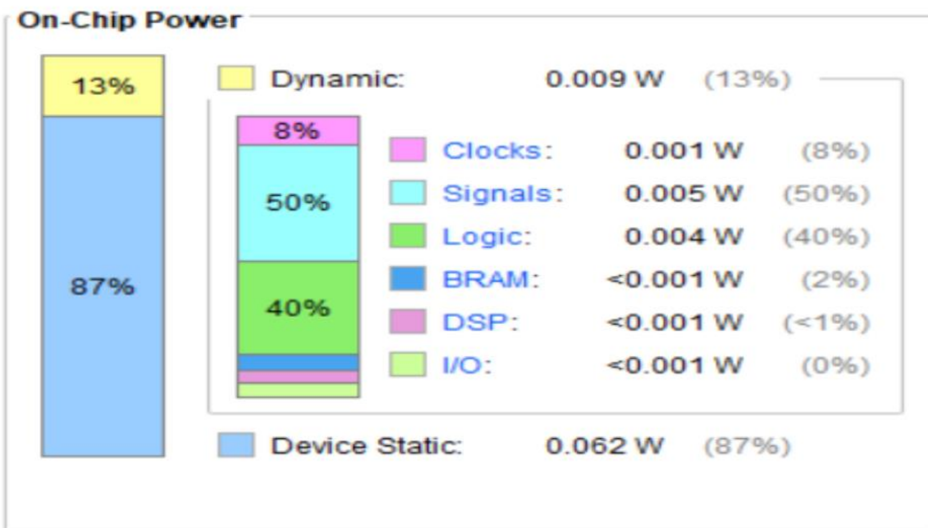

Fig. 13: On Chip Power

CONCLUSIONS

A large increase in the autonomy of the device could be identified with the replacement of the components. One of the most important features is that it has a full-custom microprocessor. Having a microprocessor with these characteristics allows us to have the possibility of increasing operating times even more. Currently the CC2541 module is in continuous use since the cloud request technique [ref paper efficiency] is applied which allows us to turn on the device by request.

One of the next objectives is to be able to move to the implementation of the microprocessor in some silicon technology. This challenge would allow us to increase the efficiency of its energy consumption.

Thanks to the increase in operating days, this device can be used for new treatments in the medical area. By having a device with 8 days of continuous operation we can have a very strong tool for monitoring diabetes.

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