Tekhnê
January - June 2020, Vol. 17, No. 1, pp. 37 – 50

ISSN 1692-8407

Design of the control system for a thermal waste plant

Diseño del sistema de control de una planta de residuos térmicos

Diego F. Rondón M.[1] and Heidy M. Rodríguez C.[2]
[1]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
dfrondonm@correo.udistrital.edu.co
[2]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
hemrodriguezc@correo.udistrital.edu.co

This article deals with the development of the design of a temperature control system for a vegetable waste treatment plant, specifically the Verilog hardware description language is used on a PSoC CY8-CKIT-059. The system has three stages of information handling, in the first instance the conversion of a decimal voltage value represented by a pulse to bits is performed, then a component in charge of the transformation entered in bits to a new bit sentence that will feed the terminals of different seven-segment displays that make up the graphical interface of the system will be added.

Keywords: Control, digital electronics, system, temperature, Verilog

Este artículo trata sobre el desarrollo del diseño de un sistema de control de temperatura para una planta de tratamiento de desechos vegetales, específicamente se usa el lenguaje de descripción por hardware Verilog sobre un PSoC CY8-CKIT-059. El sistema cuenta con tres etapas de manejo de información, en primera instancia se realiza la conversión de un valor de tensión decimal representado por un pulso a bits, luego de ello se agregara un componente encargado de la transformación ingresada en bits a una sentencia de bits nueva que alimentara los terminales de distintos displays de siete segmentos que componen la interfaz gráfica del sistema.

Palabras clave: Control, electrónica digital, sistema, temperatura, Verilog

Article typology: Research

Received: June 9, 2020
Accepted: June 26, 2020

Research funded by: Universidad Distrital Francisco José de Caldas (Colombia).

How to cite: Rondón, D., Rodríguez, H. (2020). *Design of the control system for a thermal waste plant*. Tekhnê, 17(1), 37 -50.

ISSN 1692-8407

Introduction

Most physical and chemical reactions in nature are temperature sensitive, so temperature control is highly relevant in industrial processes (Calderón et al., 2017). Temperature controllers that are based on digital circuits have several advantages, such as a high level of accuracy, a high level of programmability, and adaptability (Mondal & Pal, 2013). The decisions that result from the analysis of the temperature in a system can determine whether a process is running correctly or not. Such a level of importance demands that the measurement process meets standards of high accuracy, high resolution, and the lowest possible uncertainty, hence the need for control technologies such as microcontrollers.

To analyze and digitize the information received from the outside, sensors must be used (Galvis & Madrid, 2016; Reyes & Gerena, 2018). The sensors perform the function of discretizing the information and translating it into a language that can be highly codified by a machine or programming software (Córdoba & Plazas, 2015; Moreno & Páez, 2017). After that, the encoded information must be retransmitted again into a language that can be easily understood. This creates the need to make use of a graphical interface.

The design principle of temperature sensors is based on the components or materials used for their construction. This type of component must have an appreciable response to temperature changes in different media, it must be taken into account that some materials lose their physical properties with constant temperature changes (López, 2014).

Some of the main needs to be met by the sensors are:

- Compatibility with digital language.
- Occupy the smallest possible area.
- Low power consumption.
- Cover a wide temperature range.
- Easy calibration.
- Digital output.
- High precision (Álvarez & Gómez, 2019).

In addition to temperature measurement, the measurement of periods is also vital in industrial processes (Riaño et al., 2012). Because temperature changes in defined time intervals; often allow obtaining highly elaborated products, or simply to achieve that the properties of the element to which the temperature change is applied change in favor of a pre-established purpose.

This complex level of real-time information capture has triggered a commercial race for the production of highly reliable devices, which use the technologies corresponding to their time. In general, the first devices used analog technology during the capture and manipulation of information; with the digital revolution of the last part of the last century, digital design has gradually replaced this technology (Vásquez & Martínez, 2011).

One of the advantages of this accelerated change in technology is that digital language, in most cases binary, can be easily encoded by machines or digital devices. The information acquired in the digital medium can get to have a correct interpretation in the communication system used by humans. This interaction of information is made possible because coding languages, such as binary language, allow the manipulation of data using Boolean algebra. This process leads to the construction of logic circuits in hardware description languages, the development of which is the foundation of the devices mentioned above (Olarte et al., 2007).

More particularly, the hardware description language is commonly used to model electronic systems. This description language supports the design of systems such as temperature control to be implemented. They also can make a mix between analog and digital technology, which is useful since as mentioned above most sensors are a digital response to temperature changes.

Next, and taking into account the previous considerations, we will design a control system in a hardware description language, to control the temperature in a plant that processes vegetable waste, it is required, and as we mentioned before that the physical properties of the waste change at the convenience of the process which will be a carbonization process. Likewise, it is of vital importance to enhance the design of the control of the exposure time of the material to different temperatures. The design of the system will be carried out in stages and sequential order. At the end of the process, there must be a digital display in which the information and the status of the system can be visualized according to the stage of the process.

The process mentioned above refers to the thermal treatment of biomass for the generation of activated carbon. Since it is indispensable to have control over the temperature of the furnace where the organic elements will be calcined, the design and temperature control system will be created to reach the desired temperature at each stage of the process.

Problem statement

How to design an autonomous system through hardware description language for the control of a plant that processes vegetable waste?

Control systems are fundamental in the operation of processes since they allow the manipulation of the different variables intrinsic to the process. The correct control of these variables increases the probability of improving parameters such as effectiveness and efficiency in execution. Similarly,

ISSN 1692-8407

there are manufacturing and material handling processes where it is essential to have indirect and automatic control systems because sometimes the human being is not suitable to run the control process.

In a more particular way there are processes whose result depends primarily on the application of heat energy at high temperatures, ie the control of the temperature variable, such example: Metallurgical foundry, glass manufacturing, cooking food, etc. That is, from the simplest to the most complex processes, it is important to have the highest possible accuracy in the control of temperature changes to avoid undesired results.

As an example, one of the processes for which temperature control is important is the carbonization of vegetable waste in thermal treatment plants. There, the temperature of the furnace varies in different scales and the different time intervals necessary for the treatment of the waste must be controlled; according to the above and as the human being does not resist the temperature levels to which the waste is exposed, besides that it induces error in the control of periods during the process. It is necessary to design indirect control systems that provide reliable information in real-time inducing the minimum possible error, safeguarding the safety of operators and the quality of the final product.

The systems that offer this level of reliability are mostly digital systems, which operate based on a general programming language. For this reason, to satisfy the need to exercise control over processes where the human being is highly inefficient, it is essential to create a control system from languages such as hardware description, which can be widely used in the design of automatic systems.

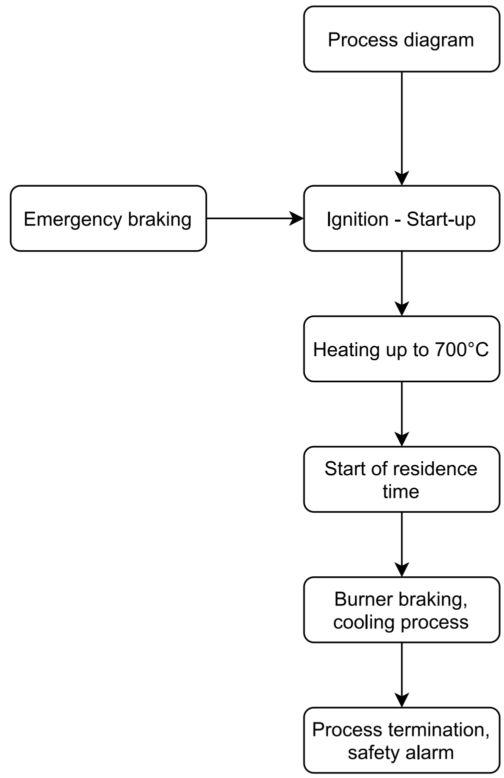
Design requirements

An autonomous system is to be designed in Verilog for the control of a plant that thermally processes vegetable waste. The processing includes the heating of the vegetable in an oven for a certain time (residence time). The following are the characteristics of the plant and the system to be implemented.

1. The plant has a kiln. The oven operates with a natural gas burner. When the start button is pressed, the system must light the burner and keep it on until the maximum temperature sensor (STMAX) indicates with a logical one that 700 degrees Celsius has been reached. The rotation motor should also be turned on. At this point, the residence time starts counting. If the temperature drops below 500 degrees Celsius (which is indicated by a logic one from the minimum temperature sensor STMIN) the burner should be restarted. The material in the oven should be held between the maximum and minimum temperatures for four hours.

Figure 1

Process diagram.



2. At the end of the four hours, turn off the burner, turn on the yellow alarm (sound and light, OAA), and wait for the safety temperature sensor (STSEG), which sends a signal when the temperature is below 100 degrees Celsius. At this time the rotation motor should be turned off, and when the rotation sensor S M R indicates that the oven has stopped, the green alarm (sound and light OAV) should be turned on. This indicates the end of the process.

3. An emergency stop pushbutton should be implemented, which shuts down the burner and the rotation motor.

4. All pushbuttons must-have software implemented an anti-rebound system.

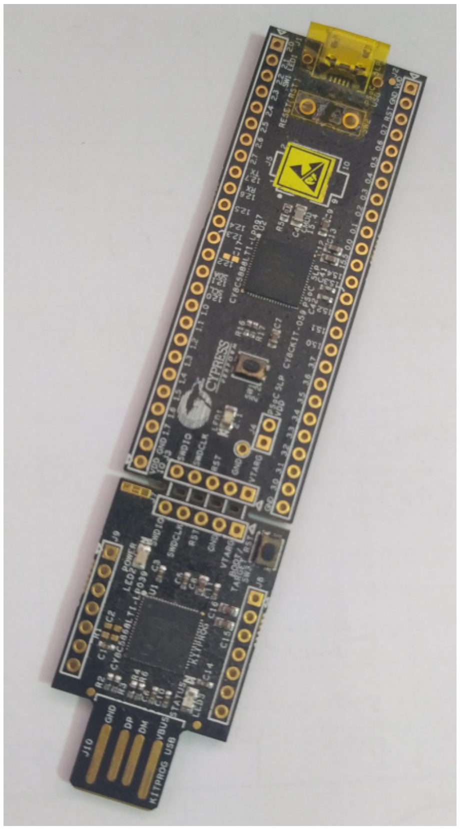
5. A display must be implemented to visualize the information and status of the system.

Fig. 1 shows the process diagram.

ISSN 1692-8407

Figure 2

PSoC CY8CKIT-059.



Methods

To build the control system according to the required specifications, we took into account three fundamental design stages.

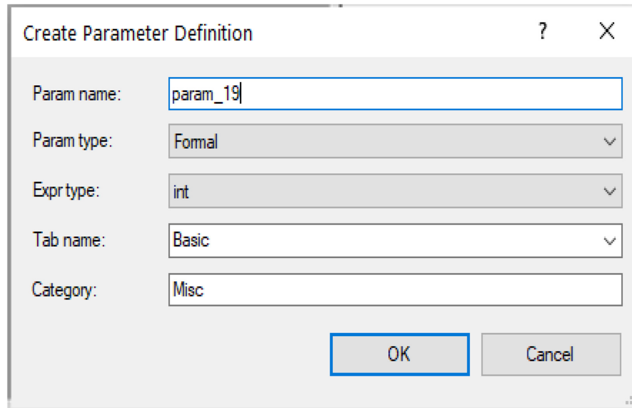
Control system

For the design of the temperature control system, we will use the VEerilog hardware description language, a widely understood language compatible with the PSoC CY8CKIT-059, a controller easily available on the market and highly versatile for the design of digital systems (Fig. 2).

The working software to be used will be PSoC Creator, a free and easy to download online software, the only requirement for its acquisition is to register on the Cypress platform. First of all, the software is started and the version of the device that is available is selected. Then proceed to the creation of the component, it should be noted that the hand must run a real hardware parameter as shown below (Fig. 3). The selection of the Hardware true parameter allows the physical connections on the device (Fig. 4).

Figure 3

Parameter creation.



Subsequently, the component is created. The component must take into account the relationship of inputs and outputs that make up the system. As we can see in Fig. 5, on the left side are the inputs that generate state variations within the component, while on the right side are the outputs of the system that control the stages of the burn cycle. These outputs are directly affected by the internal configuration of the hardware description system.

Below you can see how to generate the work interface to design the language in Verilog (Fig. 6). To manipulate the digital information produced by the inputs and outputs, these must be identified in the Verilog code. It is also necessary to select the type of variable that corresponds to the inputs and outputs. In this case, the inputs are of type WIRE, i.e. hardware connection, and the outputs are of type REG, i.e. information storage.

The functional blocks of the code built in the Verilog language are shown below (Figs. 8 to 10).

At this point in the process, the first stage is finished (Fig. 10). The container has reached the maximum allowable temperature. When the maximum temperature sensor is activated, the burner is de-energized, initiating the cooling process or second stage (Fig. 11).

The temperature starts to drop, then the maximum temperature sensor is deactivated and the intermediate temperature sensor is activated, which generates a condition to activate the minimum temperature sensor allowed for the heating process, 500 degrees Celsius (Fig. 12).

When the temperature decreases to 500 degrees, a temperature pilot light of this sensor also lights up, indicating the temperature range of the process. The material inside the furnace will remain in a residence state between the minimum and maximum temperatures for four hours. This

ISSN 1692-8407

Figure 4

Hardware parameter selection.

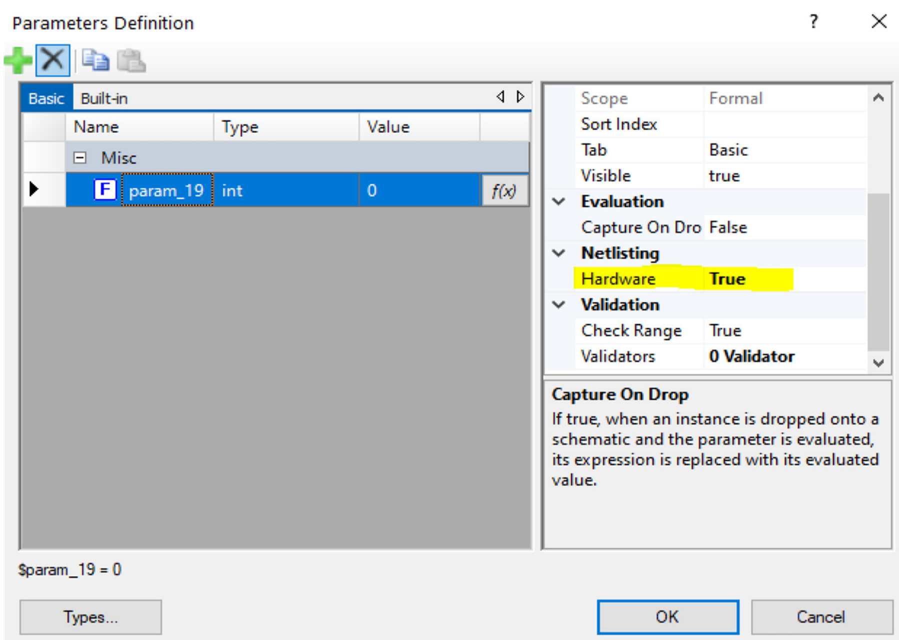
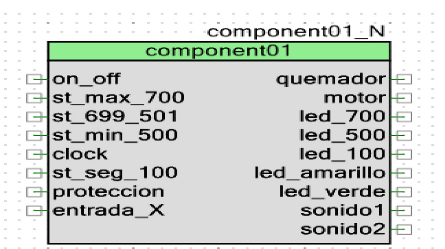


Figure 5

Component creation.



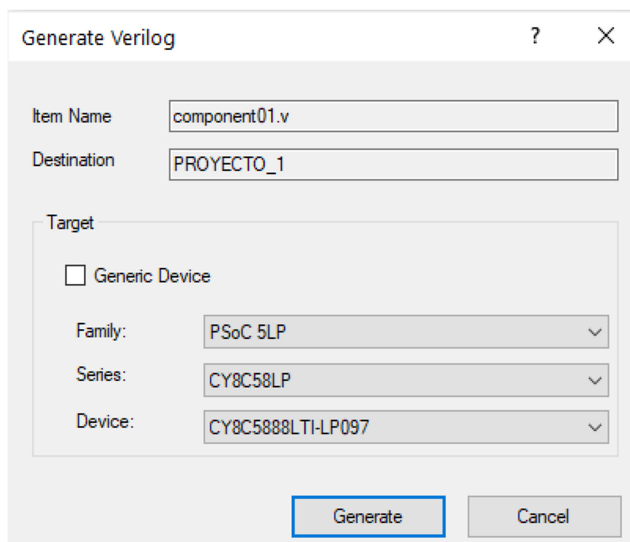
CLOCK signal is simulated for ease of use by a simple switch (Fig. 13).

To make the timer control interrupt the heating process and stop the burner at any stage, a condition must be generated for each possible position of the temperature sensors, then we will show the CLOCK interruption system to reach the third stage (Figs. 14 and 15).

At this point in the process, the residence time has stopped, i.e. the material is ready to continue its transformation process. When the pre-set time is stopped, the burner and all the previous sensors are switched off and a yellow indicator LED lights up (Fig. 16).

Figure 6

Verilog code generation.



The temperature can now be lower than 500 degrees Celsius, a safety sensor of 100 degrees Celsius is ready to act and when the temperature reaches this value, its

Tekhnê
January - June 2020, Vol. 17, No. 1, pp. 37 – 50

ISSN 1692-8407

Figure 7

Definition of inputs and outputs.

```
//DECLARACION DE LAS VARIALES DE ENTRADA Y DE SALIDA

module component01 (
      output reg led_100,
      output reg led_500,
      output reg led_700,
      output reg led_amarillo,
      output reg led_verde,
      output reg motor,
      output reg quemador,
      output reg sonido1,
      output reg sonido2,
      input  wire  clock,
      input  wire entrada_X,
      input  wire on_off,
      input  wire proteccion,
      input  wire st_699_501,
      input  wire st_max_700,
      input  wire st_min_500,
      input  wire st_seg_100
);

      parameter param_19 = 0;
```

Figure 8

Absolute zero condition in the circuit.

```
// CUANDO TODOS LOS ESTADOS PRODUCIDOS POR LAS
//ENTRADAS ENTREGUEN UN 0 LAS SALIDAS SERAN 0

        if ((on_off ==0) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 0) &&
        ( entrada_X == 0) &&  ( proteccion  == 0))
          begin
              quemador = 0 ;
              motor    = 0 ;
              led_700  = 0 ;
              led_500  = 0 ;
              led_100  = 0;
              led_amarillo = 0;
              led_verde= 0;
              sonido1  = 0;
              sonido2  = 0;
          end
```

characteristic pilot light comes on and the engine stops (Fig. 17).

When the motor stops and reaches the minimum safe temperature, the pilot light, and an alarm light up, a signal designed to warn operators that the cycle is over (Fig. 18).

Similarly, there must be an emergency stop system; in general, when this push button is pressed, the process must be completely stopped. An effective interruption of the circuit must be generated. This is achieved with a conditional in which all the outputs are taken into account (Fig. 19).

Figure 9

Burner ignition process.

```
// SE INGRESA LA SENTENCIA ELFE IF PARA QUE SE LLEVE A CABO  LA SIGUIENTE INSTRUCCION
// SE GENERA  UN UNO LOGICO EN LA ENTRADA ON_OFF EL CUAL ENCIENDE EL QUEMADOR

            else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
                    ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 0) &&
                    ( entrada_X == 0) &&  ( proteccion  == 0))
                begin
                    quemador = 1 ;
                    motor    = 0 ;
                    led_700  = 0 ;
                    led_500  = 0 ;
                    led_100  = 0;
                    led_amarillo = 0;
                    led_verde= 0;
                    sonido1  = 0;
                    sonido2  = 0;

                end
```

Figure 10

Maximum temperature, clock start, burner shutdown.

```
// EN LA ETAPA 1 EL SENSOR ST_MAX_700 GENERA UN UNO LÓGICO CUANDO LA
// TEMPERATURA DEL HORNO LLEGA A LAS 700°C Y EL TEMPORIZADOR SE
// ENCIENDE PARA HACER LA CUENTA REGRESIVA DE 4 HORAS
// HACIENDO QUE EL MOTOR Y EL LED DE 700°SE ENCIENDAN Y EL QUEMADOR SE APAGUE


    else if ((on_off ==1) && (st_max_700  == 1)&&(st_699_501 == 0)&&
            ( st_min_500 == 0) && ( clock == 1) && ( st_seg_100 == 0) &&
            ( entrada_X == 0) &&  ( proteccion  == 0))

        begin
            quemador = 0 ;
            motor    = 1 ;
            led_700  = 1 ;
            led_500  = 0 ;
            led_100  = 0;
            led_amarillo = 0;
            led_verde= 0;
            sonido1  = 0;
            sonido2  = 0;
        end
```

Analog-to-digital conversion

The graphical interface of the system is responsible for warning the operators of the state in which the process is, specifically for this case the graphical interface must show in different displays type seven segments the temperature value at which the process is. To achieve this task within the control device must be a tool that is capable of digitizing information from environmental variables such as temperature to digital information of a reliable character and with the least possible error.

Accordingly, the device must contain within itself a transducer element in charge of translating the temperature

ISSN 1692-8407

Figure 11

Intermediate temperature sensor application.

```
// EL SENSOR ST_699_501 REPRESENTA EL RANGO DE TEMPERATURA ENTRE 699° Y 501°C
// PARA ESTA SEGUNDA ETAPA SE ESPERA QUE LA TEMPERATURA DEL HORNO DISMINUYA
// LO QUE GENERA UN UNO LÓGICO EN EL SENSOR ST_699_501 HACIENDO QUE SE APAGUE
// EL LED DE 700°C Y EL MOTOR CONTINÚE ENCENDIDO

else if ((on_off ==1) && (st_max_700  == 0)&& (st_699_501 == 1)&&
        ( st_min_500 == 0) && ( clock == 1) && ( st_seg_100 == 0) &&
        ( entrada_X == 0) && ( proteccion  == 0) && (motor == 1))
    begin

        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 0;
        led_verde= 0;
        sonido1  = 0;
        sonido2  = 0;
    end
```

Figure 12

ST MIN500 range, burner resetting.

```
// DEBIDO A QUE LA TEMPERATURA VA DISMINUYENDO SE TIENE UN LIMITE DE
//TEMPERATURA MÍNIMA CUANDO SE LLEGA LAS 500°.
//EN ESTE MOMENTO EL SENSOR ST_MIN_500 GENERA UN UNO LÓGICO HACIENDO
//QUE EL QUEMADOR SE ENCIENDA NUEVAMENTE Y ENCENDIENDO EL LED DE 500°C


else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 1) && ( clock == 1) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 1 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 1 ;
        led_100  = 0;
        led_amarillo = 0;
        led_verde= 0;
        sonido1  = 0;
        sonido2  = 0;
    end
```

Figure 13

Completion of residence time.

```
//  FINALIZADAS LAS 4 HORAS DE RESIDENCIA DEL MATERIAL EL SENSOR
//  DE CLOCK SE APAGARA GENERANDO UN CERO LÓGICO, HACIENDO QUE SE
//  ENCIENDA UNA LUZ AMARILLA  Y EL SONIDO OAA.
//  ESTE PROCEDIMIENTO SE REALIZARA SIN IMPORTAR EN QUE RANGO
//  DE TEMPERATURA SE ENCUENTRA EL HORNO, LO QUE SE REPRESENTA EN
//  LOS SIGUIENTES 4 CONDICIONALES.


else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 1;
        led_verde= 0;
        sonido1  = 1;
        sonido2  = 0;
    end
```

Figure 14

Interruption at 700 degrees and interval.

```
else if ((on_off ==1) && (st_max_700  == 1)&&(st_699_501 == 0)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 1;
        led_verde= 0;
        sonido1  = 1;
        sonido2  = 0;
    end

else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 1)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 1;
        led_verde= 0;
        sonido1  = 1;
        sonido2  = 0;
    end
```

value into another physical variable. For this specific case, we will select a thermocouple in charge of translating the thermal sensation into an appreciable potential difference between two terminals.

For this reason, it is important to highlight the functionality of these digital devices (López, 2014). The principle of operation of thermocouples can be described in that they consist of two wires of different metals joined at a measuring junction. As soon as the wires cross a region where the temperature changes, an electromotive force or e.m.f., also known as thermo-voltage, is generated in them. This phenomenon is called the Seebeck effect which has a typical magnitude of about 10 to 40 μV/C depending on the coefficients of the thermocouple wires and the temperature difference across the thermocouple wires and the temperature difference along their total length.

Thermocouple selection

For this particular type of project, the K-type thermocouple is more than satisfactory in terms of the temperature range. The type K thermocouple, made of Nickel-Chromium (chrome)/Nickel-Aluminum (constantan), is recommended for working temperatures from -200 degrees Celsius to +1270 degrees Celsius. Its response has a linear

ISSN 1692-8407

Figure 15

Interruption at 500 degrees.

```
else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 1) && ( clock == 0) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 1;
        led_verde= 0;
        sonido1  = 1;
        sonido2  = 0;
    end
```

Figure 16

Safety sensor.

```
else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 1) && ( clock == 0) && ( st_seg_100 == 0)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 1 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 1;
        led_verde= 0;
        sonido1  = 1;
        sonido2  = 0;
    end
```

behavior with a sensitivity of 41 μV/C (López, 2014) (Fig. 20).

Analog/digital conversion module

In a more simplified way, it can be stated that a digital-analog conversion module is a converter of a continuous signal (voltage) which is translated into a binary number of n number of bits (discrete voltage values) to be easily manipulated by a digital device. In our case, using the hardware description language Verilog we apply to the PSoC.

Figure 17

Safety sensor activation - motor off.

```
// EN LA TERSERA ETAPA  LA TEMPERATURA DEL HORNO DECIENDE
// HASTA LLEGAR A LOS 100° C HACIENO QUE EL SENSOR DE ST_SEG_100
// ENVIA UN 1 LOGICO ENCENDIENDO EL LED DE 100°C Y APAGANDO EL MOTOR

else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 1)
        && ( entrada_X == 0) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 0 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 1;
        led_amarillo = 0;
        led_verde= 0;
        sonido1  = 0;
        sonido2  = 0;
    end
```

Figure 18

Motor stop end of cycle.

```
// FINALMENTE CUANDO EL MOTOR SE DETIENE SE ENVÍA UNA SEÑAL DONDE
// SE ADVIERTE QUE YA EL MATERIAL ES OPERABLE ENCENDIENDO UNA LUZ
// VERDE Y EL SONIDO OAV


else if ((on_off ==1) && (st_max_700  == 0)&&(st_699_501 == 0)&&
        ( st_min_500 == 0) && ( clock == 0) && ( st_seg_100 == 1 )
        && ( entrada_X == 1) &&  ( proteccion  == 0))
    begin
        quemador = 0 ;
        motor    = 0 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 0;
        led_verde= 1;
        sonido1  = 0;
        sonido2  = 1;
    end
```

The development of the temperature control system that we exemplify throughout this report will perform the design of an ADC conversion model, After selecting the thermocouple, through the sensitivity parameter of the same perform a rule of three that allows us to know how much voltage is equivalent to the working temperatures of the sensors (Fig. 21).

In Fig. 21 we can see the block converter of the voltage value to four-bit outputs. For this converter, the process of designing the code in the hardware description language must be followed as shown below (Figs. 22 and 23).

Figure 19

Operation of the emergency pushbutton process stop.

```
// CUANDO AL SENSOR DE PROTECCION LE INGRESE
// UN UNO LOGIOCO TODOS LOS ELEMENTOS DEL HORNO
// SE APAGARAN.

else if  ( proteccion  == 1)
    begin
        quemador = 0 ;
        motor    = 0 ;
        led_700  = 0 ;
        led_500  = 0 ;
        led_100  = 0;
        led_amarillo = 0;
        led_verde= 0;
        sonido1  = 0;
        sonido2  = 0;
    end
```

Figure 20

General characteristic curve termoupla type K (Msa, 2020).

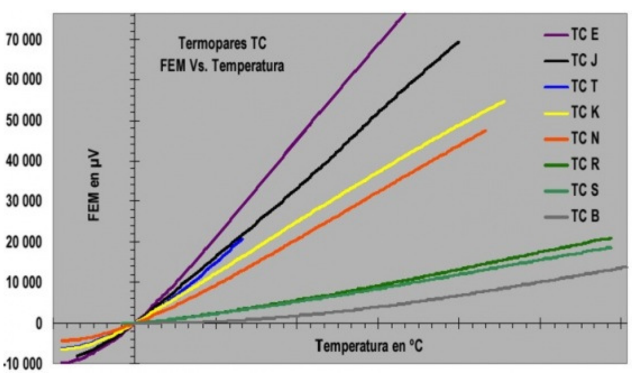


Figure 21

ADC component.

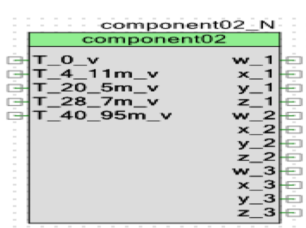


Figure 22

Definition of inputs and outputs.

```
module component02 (
        output reg w_1,
        output reg w_2,
        output reg w_3,
        output reg x_1,
        output reg x_2,
        output reg x_3,
        output reg y_1,
        output reg y_2,
        output reg y_3,
        output reg z_1,
        output reg z_2,
        output reg z_3,
        input  wire T_0_v,
        input  wire T_20_5m_v,
        input  wire T_28_7m_v,
        input  wire T_4_11m_v,
        input  wire T_40_95m_v
 );
        parameter param_19 = 0;
```

Figure 23

First conditional inputs on low outputs on low.

```
// SE REALIZÁ EL PRIMER CONDICIONAL
// SI LAS TODAS ENTRADAS ENTREGAN ENTREGAN UN CERO LÓGICO , LAS SALIDAS SERÁN TODAS CERO
        begin
            if ((T_0_v ==0) && (T_4_11m_v == 0)&& (T_20_5m_v  == 0)&&(T_28_7m_v == 0) &&(T_40_95m_v == 0))
                begin
                    w_1 = 0 ;
                    x_1 = 0 ;
                    y_1 = 0 ;
                    z_1 = 0 ;
                    w_2 = 0 ;
                    x_2 = 0 ;
                    y_2 = 0 ;
                    z_2 = 0 ;
                    w_3 = 0 ;
                    x_3 = 0 ;
                    y_3 = 0 ;
                    z_3=  0 ;

                end
```

Graphical interface

After translating the voltage values into digital information, we proceed to build the graphical interface. In this case, we build a component configured with the `case` command (Figs. 24 to 28).

When creating the component, it should be made clear that the input is a four-bit value produced at the output of the ADC designed earlier (Fig. 29).

In the configuration of the module in Verilog, it must be clarified that both inputs and outputs will be represented in groups of bits, therefore their definition is made as shown in Figs. 29 and 30.

© Universidad Distrital Francisco José de Caldas
ISSN 1692-8407

Figure 24

Bit output protection temperature in binary.

```
// SE REALIZA EL SEGUNDO CONDICIONAL EN CUAL SE INDICA QUE CUANDO LA ENTRADA T_4_11m_v
 // (ESTA REPRESENTA LA TEMPERATURA DE 100°) SE ENCUENTRE EN ALTO LAS SALIDAS
 // DEBEN REPRESENTAR UN EL NUMERO CIEN EN NÚMEROS BINARIOS 0001 0000 0000

        else if ((T_4_11m_v == 1)&& (T_20_5m_v  == 0)&&(T_28_7m_v == 0) &&(T_40_95m_v == 0))
            begin
                w_1 = 0 ;
                x_1 = 0 ;
                y_1 = 0 ;
                z_1 = 1 ;
                w_2 = 0 ;
                x_2 = 0 ;
                y_2 = 0 ;
                z_2 = 0 ;
                w_3 = 0 ;
                x_3 = 0 ;
                y_3 = 0 ;
                z_3=  0 ;

            end
```

Figure 25

Bit output minimum temperature in binary.

```
// SE REALIZA EL TERCER  CONDICIONAL EN CUAL SE INDICA QUE CUANDO LA ENTRADA T_20_5m_v
// (ESTE REPRESENTA LA TEMPERATURA DE 500°) SE ENCUENTRE EN ALTO LAS SALIDAS
// DEBEN REPRESENTAR  EL NUMERO QUINIENTOS EN NÚMEROS BINARIOS 0101 0000 0000

        else if ((T_4_11m_v ==0 )&& (T_20_5m_v  == 1)&&(T_28_7m_v == 0) &&(T_40_95m_v == 0))
            begin
                w_1 = 0 ;
                x_1 = 1 ;
                y_1 = 0 ;
                z_1 = 1 ;
                w_2 = 0 ;
                x_2 = 0 ;
                y_2 = 0 ;
                z_2 = 0 ;
                w_3 = 0 ;
                x_3 = 0 ;
                y_3 = 0 ;
                z_3=  0 ;

            end
```

Figure 26

Bit output maximum temperature in binary.

```
// SE REALIZA EL CUARTO CONDICIONAL EN CUAL SE INDICA QUE CUANDO LA ENTRADA T_28_7m_v
// (LA CUAL REPRESENTA LA TEMPERATURA DE 700°) SE ENCUENTRE EN ALTO LAS SALIDAS
// DEBEN REPRESENTAR  EL NUMERO SETECIENOS EN NÚMEROS BINARIOS 0111 0000 0000

        else if ((T_4_11m_v ==0 )&& (T_20_5m_v  == 0)&&(T_28_7m_v == 1) &&(T_40_95m_v == 0))
            begin
                w_1 = 0 ;
                x_1 = 1 ;
                y_1 = 1 ;
                z_1 = 1 ;
                w_2 = 0 ;
                x_2 = 0 ;
                y_2 = 0 ;
                z_2 = 0 ;
                w_3 = 0 ;
                x_3 = 0 ;
                y_3 = 0 ;
                z_3=  0 ;

            end
```

Figure 27

System overheat status bit output.

```
// SE REALIZA EL ULTIMO  CONDICIONAL EN CUAL SE INDICA QUE CUANDO LA ENTRADA T_40_95m_v == 0
// (LA CUAL REPRESENTA LA TEMPERATURA DE SUPERIORES A 700°) SE ENCUENTRE EN ALTO LAS SALIDAS
// DEBEN REPRESENTAR  EL NUMERO 999 EN NÚMEROS BINARIOS 1001 1001 1001

        else if ((T_4_11m_v ==0 )&& (T_20_5m_v  == 0)&&(T_28_7m_v == 1) &&(T_40_95m_v == 0))
            begin
                w_1 = 1 ;
                x_1 = 0 ;
                y_1 = 0 ;
                z_1 = 1 ;
                w_2 = 1 ;
                x_2 = 0 ;
                y_2 = 0 ;
                z_2 = 1 ;
                w_3 = 1 ;
                x_3 = 0 ;
                y_3 = 0 ;
                z_3 = 1 ;

            end

        end
```

The Fig. 30 shows the code designed with the `case` statement allows to enter a decimal value and then breaks it into four bits, then generate an output code statement on the PSoC pins. From there the inputs of the seven-segment display are fed. This configuration must be repeated three times to graphically display the temperature value in hundreds and tens units.

Results

To verify the result of the complete system design, we verified the outputs of the system component by component.

Verification of the control system

The verification of the control system was done using hardware, the signals given by the sensors and entered into the system were simulated through simple switches and the subsequent outputs, which are the burner, the motor, and the different pilots, were simulated simply with light-emitting diodes (LEDs). The assembly representing the inputs and outputs is shown in Fig. 31.

Fig. 31 shows the switches simulating the inputs located from left to right.

- The first switch is the Power switch.

ISSN 1692-8407

Figure 28

Creation of the component.

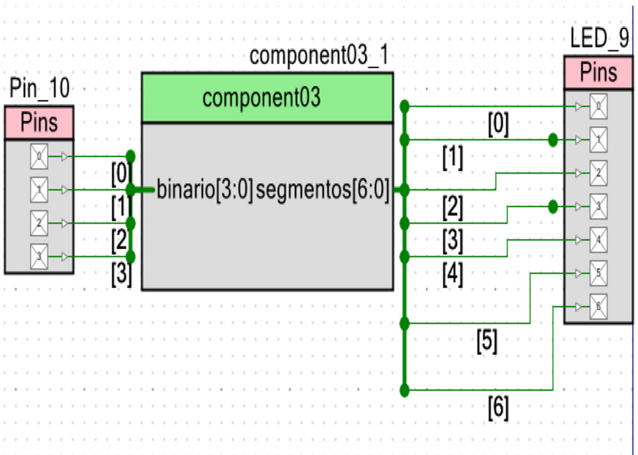


Figure 29

Definition of input and output lists.

```
module component03 (
    output reg  [6:0] segmentos,
    input  wire [3:0] binario
);
    parameter param_19 = 0;
```

Figure 30

Construction of the `case` command code.

```
always@(binario)
        begin
            case(binario)
                0: segmentos = 7'b0000001;
                1: segmentos = 7'b1111000;
                2: segmentos = 7'b0010010;
                3: segmentos = 7'b0000110;
                4: segmentos = 7'b0001100;
                5: segmentos = 7'b0100100;
                6: segmentos = 7'b0100000;
                7: segmentos = 7'b0001110;
                8: segmentos = 7'b0000000;
                9: segmentos = 7'b0001100;
                default : segmentos = 7'b1111111;

            endcase
        end

//`#end` -- edit above this line, do not edit this line
endmodule
```

- The second switch is the maximum temperature sensor ST-70O.
- The third is the intermediate temperature sensor ST-699-501.
- The fourth switch is the minimum temperature sensor ST-500.
- The fifth switch is the stopwatch switch.
- The sixth switch is the safe temperature safety sensor ST-100.
- The seventh switch represents the motor stop.

In the following (Fig. 32), we will indicate the pin assignment that was used in the system to be implemented in the device.

Since the operation of the temperature control system depends on different previous states, we couldn't perform the simulation using the Testbench tool of EDA Playground.

Analog-to-digital conversion module verification

The input and output elements of these blocks are characterized by receiving bit signals of different lengths. In this case, it is possible to perform the different possible combinations to verify the output in tools such as TestBench.

Verification of the graphical interface module

The input and output elements of these blocks are characterized by receiving bit signals of different lengths. In this case, it is possible to perform the different possible combinations to verify the output in tools such as TestBench (Figs. 36 to 38).

Conclusion

The creation of control systems using devices such as PSoC board proves to be a very functional option since such devices are easy to acquire in the market and low cost compared to other types of controllers that come to have a cost two or three times higher.

The hardware description language Verilog, the language used throughout this article is a language of great application in various fields of industrial control since its characteristics allow the design of relatively simple sequential circuits through programming code commonly used.

To carry out the construction of the control system, it was essential to define stages and conditionals. The main characteristic of the sequential circuits is mostly deepened in the subject digital circuits of the engineering courses.

It is recommended to solve any design in VHDL using a top-down approach, that is, starting with the global description of the device and then dividing it into smaller

Figure 31

Hardware assembly.

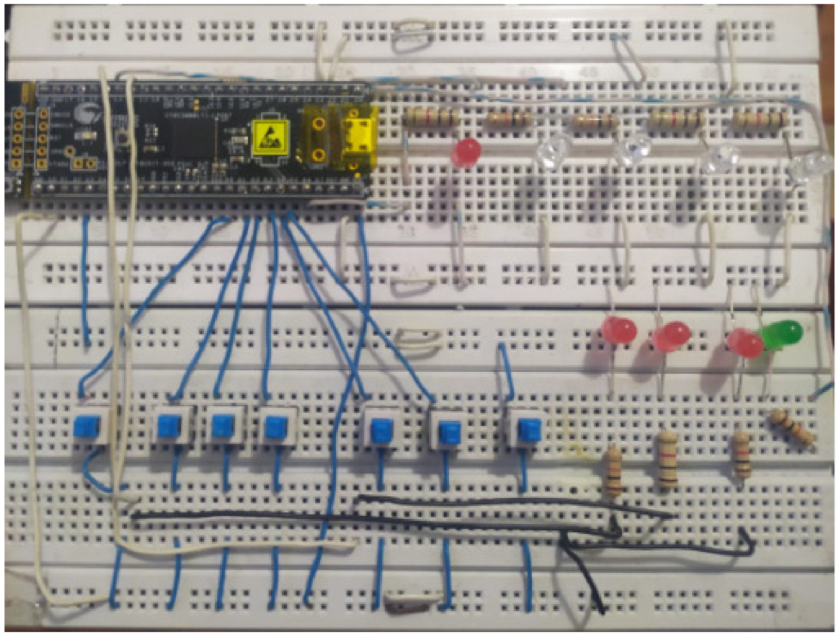


Figure 32

Pin layout in PSoC Creator.

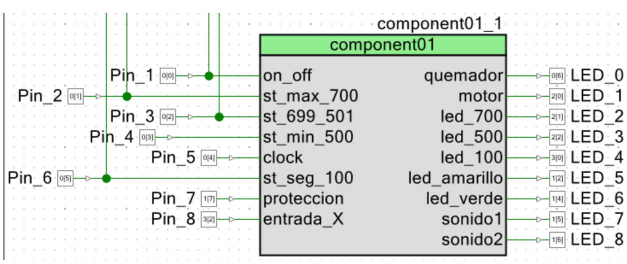


Figure 33

Definition of TestBench entries.

```
module prueba;

  reg [3:0] bcd;
  wire [11:0] seg;

  component01 siete (seg, bcd); // Instanciar el modulo
    initial begin
      $dumpfile("dump.vcd");
      $dumpvars(1, prueba);

      bcd = 4'b0000;

      #1 bcd = 4'b0000;
      #1 bcd = 4'b0001;
      #1 bcd = 4'b0010;
      #1 bcd = 4'b0100;
      #1 bcd = 4'b1000;


      #1 bcd = 4'b0000;
      $finish;

    end

endmodule
```

devices (blocks) that are then interconnected to perform the desired task. This is to be able to detect possible faults more easily and make the development process faster by designing reusable code.

Tools such as TestBench allow us to test code and its performance digitally at no cost and with great reliability. This allows us to get an approximate view of the performance of our system without having to perform the hardware verification directly, which speeds up the design process and completion of the project.

References

Álvarez, L., & Gómez, E. (2019). Circuito CMOS para el control de temperatura de sensores de gas MOX. *Ingeniería Investigación y Tecnología*, *20*(3), 1–10. https://doi.org/10.22201/fi.25940732e.2019.20n3.036

Calderón, G., Muñoz, J., & Rivera, J. (2017). Dispositivo para medir tiempo y temperatura usando un microcontrolador. *Revista Brasileira de Ensino de*

ISSN 1692-8407

Figure 34

Definition of TestBench outputs.

```
module component01 (                                SV/Verilog Design
  output reg [11:0] seg,
  input  wire [7:0] bcd
);
    parameter param_19 = 0;

//`#start body` -- edit after this line, do not
edit this line

    always @(bcd)
    begin
        case (bcd)

            0 : seg = 12'b000000000000;
            1 : seg = 12'b000000000001;
            2 : seg = 12'b000000000101;
            3 : seg = 12'b000000000111;
            4 : seg = 12'b100110011001;

            default : seg = 12'b111111111111;
        endcase
    end


//`#end` -- edit above this line, do not edit this
line
endmodule
```

Figure 35

Results using EPwave.

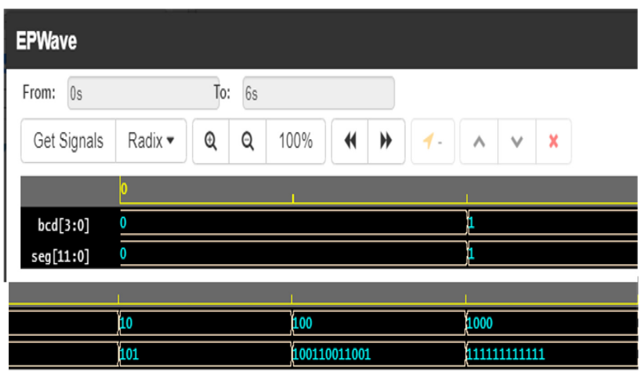


Figure 36

Definition of inputs.

```
module prueba;

  reg [3:0] bcd;
  wire [6:0] seg;

  component01 siete (seg, bcd); // Instanciar el modulo
    initial begin
      $dumpfile("dump.vcd");
      $dumpvars(1, prueba);

      bcd = 4'b0000;

      #1 bcd = 4'b0000;
      #1 bcd = 4'b0001;
      #1 bcd = 4'b0010;
      #1 bcd = 4'b0011;
      #1 bcd = 4'b0100;
      #1 bcd = 4'b0101;
      #1 bcd = 4'b0110;
      #1 bcd = 4'b0111;
      #1 bcd = 4'b1000;
      #1 bcd = 4'b1001;

      #1 bcd = 4'b0000;
      $finish;

    end

endmodule
```

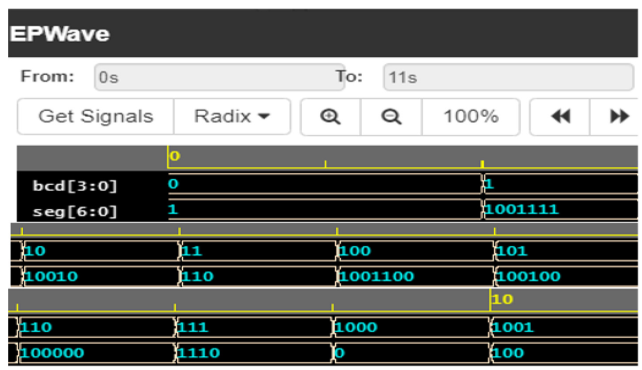
Figure 37

Definition of TestBench outputs.

```
module component01 (                                SV/Verilog Design
    output reg [6:0] seg,
    input  wire [3:0] bcd
);
    parameter param_19 = 0;

//`#start body` -- edit after this line, do not
edit this line

    always @(bcd)
    begin
        case (bcd)
            0 : seg = 7'b0000001;
            1 : seg = 7'b1001111;
            2 : seg = 7'b0010010;
            3 : seg = 7'b0000110;
            4 : seg = 7'b1001100;
            5 : seg = 7'b0100100;
            6 : seg = 7'b0100000;
            7 : seg = 7'b0001110;
            8 : seg = 7'b0000000;
            9 : seg = 7'b0000100;
            default : seg = 7'b1111111;
        endcase
    end


//`#end` -- edit above this line, do not edit this
line
endmodule
```

Figure 38

Results in the EPWave interface.



Física, *40*(2), 1–8. https://doi.org/10.1590/1806-9126-RBEF-2017-0228

Córdoba, C., & Plazas, B. (2015). Control and monitoring prototype for vehicle parking. *Tekhnê*, *12*(1), 67–72.

Galvis, J., & Madrid, J. (2016). Fuzzy control system for brushless dc motor (bldc) on embedded hardware. *Tekhnê*, *13*(2), 43–48.

López, A. (2014). Medición de temperatura mediante sensores inteligentes basados en microcontrolador. *Revista UNIMAR*, *32*(2), 1–6.

Mondal, R., & Pal, S. (2013). Microcontroller based temperature monitoring and closed loop control to study the reaction of controlled variable with respect to load changes. *Sensors & Transducers Journal*, *153*(6), 148–154.

Moreno, A., & Páez, D. (2017). Performance evaluation of ros on the raspberry pi platform as os for small robots. *Tekhnê*, *14*(1), 61–72.

ISSN 1692-8407

Msa, N. (2020). *Termocuplas*. Mediciones & Servicios Asociados. https://msa.net.co/Termocuplas/

Olarte, J., Solarte, G., & Jaramillo, J. (2007). Desarrollo de un dispositivo digital para la medición de variables ambientales utilizando un arreglo de compuertas programable en campo. *Scientia Et Technica*, *13*(34), 415–420.

Reyes, C., & Gerena, G. (2018). Mathematical modeling of a dc motor with separate excitation. *Tekhnê*, *15*(1), 13–20.

Riaño, J., Ladino, C., & Martínez, F. (2012). Implementation of fft transform on a fpga oriented towards its application in power electronic converters. *Tekhnê*, *9*(1), 21–32.

Vásquez, M., & Martínez, F. (2011). Control difuso-deslizante para convertidor dc/dc. *Tekhnê*, *8*, 31–40.