Tekhnê

Tecnología al servicio de la sociedad

Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

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La revista **Tekhnê** es una publicación institucional de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas. Posee un carácter científico, y atiende a la comunidad nacional e internacional especialista en áreas de ingenierías eléctrica, electrónica, mecánica, de sistemas, industrial y civil. Publica resultados de investigación en inglés (artículos originales e inéditos), y está completamente abierta a especialistas de todo el mundo en calidad de autores y/o lectores. Es arbitrada mediante un proceso doble ciego, con rotación continua de árbitros. La periodicidad de la conformación de sus comités Científico y Editorial está sujeta a la publicación de artículos en revistas indexadas internacionalmente por parte de sus respectivos miembros.

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La revista **Tekhnê** tiene como misión divulgar resultados de investigación realizados en el área de la ingeniería, a través de la publicación de artículos originales e inéditos, realizados por académicos y profesionales pertenecientes a instituciones nacionales o extranjeras del orden público o privado. Propende por la difusión de resultados y su acceso abierto y libre.

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Tekhnê journal is published every six months, coinciding with the academic semesters of the Universidad Distrital. It is published in July and December. The first volume of the journal was published in the first semester of 2003, maintaining its regularity to date.

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The mission of **Tekhnê** journal is to disseminate research results conducted in the area of engineering, through the publication of original and unpublished articles by academics and professionals belonging to national or foreign institutions of public or private order. It aims at the diffusion of results and their open and free access.

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Declaración de ética y buenas prácticas

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El comité editorial de la revista **Tekhnê** está comprometido con altos estándares de ética y buenas prácticas en la difusión y transferencia del conocimiento, para garantizar el rigor y la calidad científica. Es por ello que ha adoptado como referencia el Código de Conducta que, para editores de revistas científicas, ha establecido el Comité de Ética de Publicaciones (COPE: Committee on Publication Ethics) dentro de los cuales se destaca:

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En caso de detectarse algún trabajo cuyo contenido sea fraudulento, será retirado tan pronto como se conozca, informando inmediatamente tanto a los lectores como a los sistemas de indexación.

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The editorial board of **Tekhnê** journal is committed to ethics high standards and good practice for knowledge dissemination and transfer, in order to ensure rigour and scientific quality. That is why it has taken as reference the Code of Conduct, which has been established by the Committee on Publication Ethics (COPE) for scientific journal editors; outlining the following:

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• Ensuring freedom of expression.
• Maintaining the academic integrity of their content.
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• Post corrections, clarifications, retractions and apologies when necessary.

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The journal includes a description of the process for peer evaluation of each received work, and has an authors guide with this information. The guide is regularly updated and contains a link to this code of ethics. The journal recognizes the right of authors to appeal editorial decisions.

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Whenever evidence that a published work contains significant misstatements, misleading or distorted statements, it must be corrected immediately.

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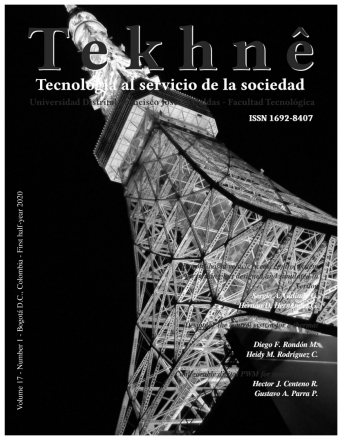

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Editorial

En marzo de este año, Colombia enfrentó un aislamiento obligatorio a causa del COVID-19, bajo la medida de emergencia sanitaria. Se trata de una enfermedad infecciosa provocada por el virus SARS-CoV-2, el cual se propaga desde la boca o la nariz de una persona infectada en forma de pequeñas partículas líquidas. En este sentido, el país, aunque algo tarde, se unió a la tendencia global de aislamiento dado el desconocimiento del virus, la ausencia de tratamientos y/o vacunas, y la letalidad en los casos más graves. Esta situación se ha extendido en varias ocasiones, y a la publicación de este número de la revista (julio de 2020) aún se mantiene.

Esta nueva situación ha planteado un cambio total de la forma en que las instituciones del país, incluidas las entidades educativas, desarrollan sus actividades diarias. Es imposible ingresar a los espacios habituales de trabajo, y una clase presencial en un salón cerrado con más de 20 estudiantes es simplemente impensable. En el caso de las instituciones de educación superior, el problema se ha enfrentado con el apoyo de las Tecnologías de la Información y las Comunicaciones (TIC), y la asistencia presencial se ha reemplazado por aulas digitales, en las que los estudiantes y docente se encuentran a distancia gracias a cámaras, equipos digitales e internet. En algunos casos las instituciones ya tenían alguna infraestructura que permitía este tipo de soluciones, en otros, las instituciones tuvieron que reinventarse rápidamente.

Por desgracia, este tipo de estrategias asumidas a las carreras y por obligación de la situación arrastra problemas no analizados con anterioridad por las entidades de educación. Además de las exigencias de conexión impuestas a los estudiantes (de los cuales no eran pocos los que carecían de conexión de datos), los docentes tuvieron que cambiar por completo sus estrategias metodológicas para adaptarse al nuevo contexto. Probablemente en un futuro cercano darán a la luz nuevos problemas relacionados con la incapacidad de socializar de los jóvenes, o su bajo rendimiento dada la inexperiencia en esquemas de evaluación de desempeño en modelos a distancia. No menos importantes son las dudas respecto a los costos de un semestre académico en una modalidad diferente a la acordada en las matrículas iniciales, o si es correcto que un programa presencial se ofrezca un en modalidad a distancia.

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Editorial

In March of this year, Colombia faced mandatory isolation due to COVID-19, under a health emergency measure. This is an infectious disease caused by the SARS-CoV-2 virus, which spreads from the mouth or nose of an infected person in the form of small liquid particles. In this sense, the country, although somewhat late, joined the global trend of isolation given the lack of knowledge of the virus, the absence of treatments and/or vaccines, and the lethality in the most severe cases. This situation has spread on several occasions, and as of the publication of this issue of the journal (July 2020), it continues.

This new situation has brought about a total change in the way the country's institutions, including educational institutions, carry out their daily activities. It is impossible to enter the usual workspaces, and a face-to-face class in a closed classroom with more than 20 students is simply unthinkable. In the case of higher education institutions, the problem has been faced with the support of Information and Communication Technologies (ICT), and face-to-face attendance has been replaced by digital classrooms, in which students and teachers meet remotely thanks to cameras, digital equipment, and the Internet. In some cases the institutions already had some infrastructure that allowed this type of solution, in others, the institutions had to reinvent themselves quickly.

Unfortunately, this type of strategy, adopted in a hurry and forced by the situation, brought with it problems that had not been analyzed before by educational institutions. In addition to the connection requirements imposed on students (not a few of whom lacked data connection), teachers had to completely change their methodological strategies to adapt to the new context. Shortly, new problems related to the inability of young people to socialize, or their low performance gave their inexperience in performance evaluation schemes in distance models, will probably come to light soon. No less important are the doubts regarding the costs of an academic semester in a modality different from the one agreed upon in the initial enrollment, or whether it is correct for a face-to-face program to be offered in a distance modality.

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Transmicable impact

Impacto Transmicable

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The problem of mobility is one of the many issues that arise in cities. For this reason, territorial planning and how to get around is a fundamental pillar for the construction of society. In Bogotá (Colombia) the issue of mobility is very complex, especially in the most remote neighborhoods. The integrated Transmilenio system tries to control the problem, however, several factors such as population growth with an average of 1.87% per year reduce its capacity. This expansion significantly affects the environment, increases congestion, the accident rate, and creates an inability of movement and accessibility. The implementation of new transportation systems is a relevant factor for proper functioning. Projects such as the Transmicable not only provide a solution to the mobility issue but also have constructions with social benefits.

Keywords: Aerial cable, environmental impact, mobility, safety, security, social impact

El problema de la movilidad es uno de los tantos que se presentan en las ciudades. Por ello la planeación del territorio y el cómo transportarse es un pilar fundamental para la construcción de sociedad. En Bogotá (Colombia) el tema de la movilidad es muy complejo, sobre todo en los barrios más alejados. El sistema integrado de Transmilenio trata de controlar el problema, sin embargo varios factores como el crecimiento de la población con un promedio de 1.87% por año reducen su capacidad. Esta expansión afecta significativamente el medio ambiente, aumenta la congestión, la tasa de accidentes, y crea incapacidad de movimiento y accesibilidad. La implementación de nuevos sistemas de transporte es un factor relevante para el buen funcionamiento. Proyectos como el Transmicable no solo da solución al tema de movilidad sino que además cuenta con construcciones con beneficio social.

Palabras clave: Cable aéreo, impacto ambiental, impacto social, movilidad, seguridad

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Introduction

In this paper, we will talk about a new form of transportation and the impact that this is leaving in the locality of Ciudad Bolivar both environmentally, socially, and in terms of mobility, because Bogota is a very large city, and there are places of difficult access such as the suburbs, people have to endure long journeys, traffic jams, poor road conditions, and insecurity, such journeys are very time consuming, as it used to happen to the inhabitants of the upper neighborhoods of Ciudad Bolivar, the daily commute just to get to the Tunal portal, which is the closest portal to the area, could take an hour or more (González & Sánchez, 2019). Currently, the time spent by each person is much less, reducing the dissatisfaction of people concerning the public transport system operating in the area. This and other problems were reduced when TransmiCable, the most innovative public transportation system in the capital, began operating and has been in operation for approximately two years.

Integral Transmicable Project

This project arose due to the need for a more viable means of transportation, which would improve the quality of life of the inhabitants of one of the most marginalized localities, such as Cuidad Bolivar. Therefore, in 2008, the idea of an elevated transportation system to solve the mobility of the upper neighborhoods of this locality began to be proposed. A year later, Mayor-elect Samuel Moreno was the first to announce a study of the project, which indicated that about 3,000 people per hour would travel in 20-person cabins and this project would have an initial cost of 120,000 million (Colombian pesos), however, the project was not consolidated and over time was put on hold because no progress was made.

In 2012, with a new administration in charge of Gustavo Petro, the idea of building an elevated transportation system was taken up again, but it was not possible to start the works since the Council of Bogotá denied the necessary resources to start the work. It was not until 2013, that the District would sign an agreement with Metro de Medellín to carry out the technical studies of the work and for this purpose an amount of 3,967 million pesos was allocated. In the same year, a date for the beginning of works was announced for the first time, which would be in June 2014 to start to operate approximately in 2015, which would decrease the travel time from one hour to approximately 13 minutes (Fig. 1). The work would increase by 10,000 million more than the amount proposed by Samuel Moreno.

In 2014, the Urban Development Institute (IDU) initiated the bidding process for the project. The winning firm would have to carry out the studies, propose designs, start the works and put the system into operation in 20 months. The cost of

Figure 1

Transmicable rendering (Editorial, 2016).

the work has already increased significantly from 130,000 million pesos to 164,400 million pesos. The plans were for the work to be completed in June 2016, but in December of this year, the time to complete the work would be increased to 35 months and the delivery date would be changed to early 2017.

In March 2015, the Urban Development Institute announced that firms interested in submitting their proposals would have until April since the contract would be awarded in May and by the end of that year they would have to start with the work, which would have certain conditions: it must have a length of 3.3 km. It will have four stations between El Tunal and El Paraíso, a capacity for 3,600 passengers per hour (600 passengers more than those projected by Samuel Moreno), and 160 cabins.

Finally, three groups were qualified to compete for the contract, and whoever was chosen would have five months to carry out the studies, designs, and respective approvals, one month to do the preliminaries, and 17 months to build it. In June of the same year, the IDU announced the business group in charge of carrying out the project, which was a temporary business cable union formed by Doppelmayr Colombia SAS, Constructora Colpatria SA, and Icein Ingenieros Constructores SAS.

In September of this year, the project is involved in an accusation of corruption in the management of the contract, where Rafael Rodriguez, a former district official in Petro's administration who was no longer in office, is facing criminal proceedings due to irregularities in contracting. This revolved around the company Doppelmayr Colombia SAS, Mayor Petro, his wife, and senior officials of the IDU and Transmilenio. Despite this, in November, Mayor Gustavo Petro signed the act to begin construction of the project and it would begin in March 2016.

The works began in September 2016, the year in which the purchase of most of the land was also carried out, in the Peñalosa administration, the budget increased again to

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Figure 2

Civil engineering of the Transmicable (Escobar, 2016).

Figure 3

Assessment of the social impacts projected for Transmicable around the station (Moyano et al., 2018).

$170,656 million and will be delivered in approximately 21 months (Fig. 2).

During its construction, the district planning secretary led the projects related to the equipment that would accompany the Transmicable to benefit the community of Ciudad Bolivar. By combining two projects, one dedicated to mobility and public transportation and the other to urban renewal, the "integral Transmicable project" was created, where a total of $240,000 million were invested.

In December 2018, the transport system began operating, which has a route of 3.34 kilometers with a duration of 13 minutes. It has 4 stations each with bicycle parking and public restrooms are portal Tunal, Juan Pablo II, Manitas, and Mirador del paraíso. The mayor's office assured that state-of-the-art technology had been implemented with elements such as solar panels, automatic doors, video surveillance system, wifi, possible communication with the central office, and others. It has 163 cabins with a maximum capacity of 10 passengers, where people will not be allowed to stand, with great comfort, thus mobilizing 3600 passengers per hour/direction. And making trips with a speed of 19 km / h. generated approximately 332 jobs that are mostly people living in the same locality, including officials, technicians, operators, etc.

Transmilenio announced the notable differences with the trunk service (buses) that currently serves the entire city, to avoid misuse of the system the turnstiles were made from the floor to ceiling, thus ensuring the payment of each passenger. The frequency of the service will be 10 seconds, which means great performance, compared to the rest of public transportation in Bogota. The means of payment is using the "*Tu llave*" card, it has the same fare as the Transmilenio trunk system and has the same benefits of transfers and subsidies, making it economically affordable. It operates from Monday to Saturday from 4:30 am to 10:00 pm, and Sundays and holidays from 5:30 am to 9:00 pm (Fig. 3).

People and Transmicable

Ciudad Bolivar, located in the southwest of Bogota, is an area that has faced different problems not only in terms of transportation and mobility. It deals with different social problems that have a variety of causes such as the partial absence of the state. This is why at the same time that the mobilization problem was thought to be solved, urban renewal was also thought of; public spaces and district buildings for the people who live around the air transport system.

The urban development institute in its citizen satisfaction report, conducted a series of surveys in 2019, on March 4, 5, and 6. In this way it was found that the educational level of citizens is mostly up to high school, the other educational levels have lower percentages (Fig. 4). Almost 90% live in houses, a little more than half have their own home and many have lived in the area for more than 10 years. In this section of the file, it is clarified that the respondents mentioned belonging to stratum 1. As the objective of the study was to evaluate the satisfaction of the inhabitants, a comparison was made during and after the project. Taking into account that this information is the result of the perception of the inhabitants, a large amount of the data showed a good inclination. Better perception in the image of the sector, public spaces, and mobility. One of the items that did not have a significant change, but equally significant was the security in the sector, therefore, people continued to live with insecurity.

Another relevant part of the surveys was the daily travel time, where it could be seen that the expectations of reducing travel time were fulfilled, the percentage of citizens who took more than an hour and a half on regular routes went from 27% to 5%. In this way, the IDU reports that 92% of those surveyed were satisfied with the project, and their opinion was that the construction of the project was necessary, useful, and convenient.

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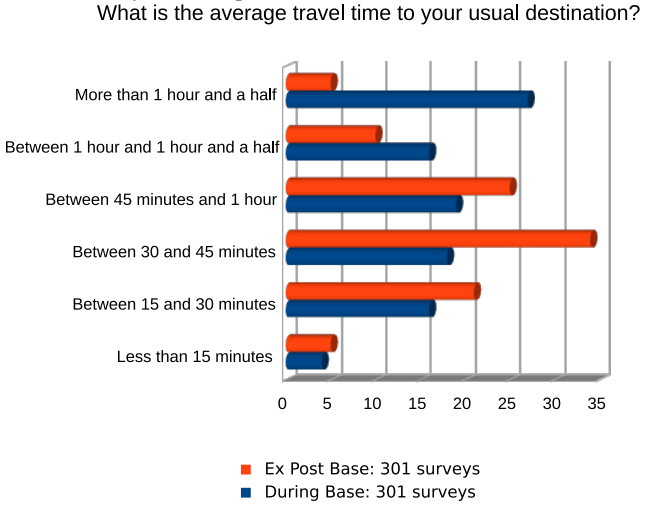
Figure 4

Citizen satisfaction report (IDU, 2019).



The positive and negative comments were based on different numbers of mentions, and despite the number of satisfaction with the project, the negative comments varied, from disagreements with the different organization and/or implements of the system (signs, lighting, turnstiles, surveillance cameras, etc.) to problems with the execution of the project (schedule, frequency, compliance with the projects in conjunction with Transmicable and fares).

The mayor's office of Bogota leads the program of good practices, which, as its name implies, is everything that generates wellbeing, based on four criteria: effectiveness, innovation, sustainability, and. In this case, the project is referred to as a good practice.

The Transmicable construction system, using pylons, allowed the creation of the facilities, with an investment of approximately $134 billion. The district planning secretary defined the architectural guidelines for each of the works, as well as other logistical and organizational aspects.

There are 26 works, community halls, cultural centers, the museum of the self-constructive city, the superCADE of Ciudad Bolivar, parks, the viewpoint and pedestrian walkway, a day center, and commercial plazas. Strategies were also planned, such as the habitARTE social inclusion program by the district habitat secretary, which through urban art would create social inclusion and physically improve the neighborhoods of Ciudad Bolivar. There were also resettlement processes to protect and avoid inconveniences for the citizens of the sector.

Social benefits go hand in hand with the construction of these works. Citizen attention where there was none, encouragement of good habits, such as culture, art, and education for vulnerable populations such as youth and children, in the different spaces and/or places provided by the district entities. And the creation of public spaces where there were none (Langellier et al., 2019).

With the arrival of the Transmicable project, the inhabitants of Ciudad Bolivar, specifically the people of the upper neighborhoods, were in expectation, they had many doubts about the service, how will it be, how fast will it travel, how many people will fit in a cabin, will it be very high, will it be sustainable, all these questions began to be murmured among the inhabitants as they were at the gates of a new project in local terms, All these questions began to murmur among the inhabitants since they were at the gates of a new project in local terms, quickly the Transmicable was well received by the inhabitants, it is a fast, quiet and efficient trip through the air pleased the people who previously spent a certain amount of time (about an hour) to get down from the high neighborhoods to take transportation to their jobs and now with this means of transportation the time it takes to travel is approximately 14 minutes.

Undoubtedly, the Transmicable has considerably improved the entire sector, both in terms of mobility and social, environmental, urban, and security aspects, since the project is not only the aerial cable as such, but also goes hand in hand with an urban development that benefits the sector through which the Transmicable passes; parks, supercades, community halls, community centers and others that guarantee a safe and comfortable space for the citizens, but most of all for the residents of this locality.

Among the benefits that this project currently generates for the community are:

- A savings of approximately $8.8 billion per year for users, which corresponds to the reduced travel time.
- A reduction of approximately 750.51 tons of carbon dioxide equivalent per year.
- Reduction of traffic accidents estimated at 119 fewer cases per year.
- Better territorial organization and therefore greater tourist attraction for people outside the community, with the artistic initiatives linked to it, such as the Urban Art Corridor.
- The better economy within the locality and the production and obtaining of direct and indirect jobs around the cable.
- Urban growth with the integration of facilities in the area of greatest influence of the stations with a Centros Día, SuperCade, public parks, centers for the elderly, and cultural centers, among others.

For Transmicable to be certified by the national environmental licensing authority (ANLA) that the equipment is creditable for sales tax (VAT) exclusion, it would have to meet certain requirements:

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Figure 5

Start of operations Transmicable (Colprensa, 2018).

Figure 6

Start of operations Transmicable (Caracol, 2019).

- Must be specifically intended to: recycle and process garbage or waste (the machine includes washing, separating, recycling and extrusion); for the purification or treatment of wastewater, atmospheric emissions, or solid waste; for the recovery of rivers or basic sanitation to achieve environmental improvement.
- Correspond to imported equipment and/or machinery that is not produced in the country.
- They must be part of a Program approved by the Ministry of Environment (Article 428 paragraph f) of the Tax Statute and Decree 1625 of 2010).

With the implementation of this project, it is expected that environmental benefits will be obtained in terms of reducing the number of atmospheric emissions generated by the different means of transportation already existing in the city (Fig. 5):

- 5,192.30 Tons of CO2eq/year.
- 0.474 Tons of PM10/year.

Finally, these environmental benefits will be achieved due to the reduction in the consumption of fossil fuels, especially diesel, which has been estimated at 162,249.11, generating a reduction in energy demand of approximately 15,764,840 KWh/year.

What Problems in the Ciudad Bolivar Sector Have Decreased Since Transmicable Began Operating?

It is considered the most problematic area of Bogotá. All the social and economic difficulties are centered there, due to the scarce representation of governmental units. It is the area of the capital with the largest displaced population (26% of the total population). Although the majority of the population is divided into socioeconomic strata 1 and 2, 17% is below poverty.

In general, the houses are invasions, built by hand with materials such as cans, bricks, wood, and tiles without the need for structural analysis. Children have very few places to play and it is dangerous for them to go alone to the few parks or recreational areas because there are many criminal groups and even satanic sects.

In addition, the city is located in the hills at the southern end of the city and consists of undeveloped areas at high risk of landslides. This area covers a large part of Bogotá's rural area and many of its inhabitants are still farmers. Because of this semi-urban aspect, guerrillas and paramilitary groups have areas of control that are difficult to identify. Violence is one of the main characteristics and the place with the highest mortality rate and medical care.

Similarly, school coverage is one of the lowest in the capital district. A significant percentage of children cannot attend classes due to the lack of places in district schools and the few private schools are not accessible due to lack of resources. For this reason, many children are left home alone and have little contact with their parents who generally work long hours.

For these reasons, Mayor Enrique Peñalosa saw the need to build civil works and provide training to the inhabitants of this locality to improve their quality of life (Fig. 6).

26 works related to Transmicable were carried out to promote culture, economy, and tourism in the locality (Fig. 7). Some of the works are:

- Recreation and sports: 5 parks including courts, green areas, playgrounds, playgrounds, squares, furniture, and signage. Zonal parks were built by the IDRD, such as the Illimani park, and neighborhood parks were built by the local mayor's office, such as the Pilona park.
- Illimaní walkway and viewpoint: A viewpoint would be built because Cuidad Bolívar has one of the best views over Bogotá, and also seeks to prevent deaths due to earthquakes due to the location of the homes

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Figure 7

Transmicabable as an engine of progress and development for the district of Ciudad Bolívar (Bogotá) (Cuevas, 2019).

of a group of inhabitants. However, with the system already operating for almost two years, the work has not been delivered and is planned to be delivered in mid-2020. As for the pedestrian walkway, it connects several places such as green areas and public spaces.

- SuperCADE Manitas: It was in charge of the general secretary of the mayor's office of Bogota. It is considered one of the most modern in Bogota and has other services aimed at social recreation.

- The museum of the self-built city: The museum will tell the story of how Bogota grew between the years 1938 and 2014.

- Cultural centers and libraries: Approximately 1,000 literature and informative books will be available at these stations.

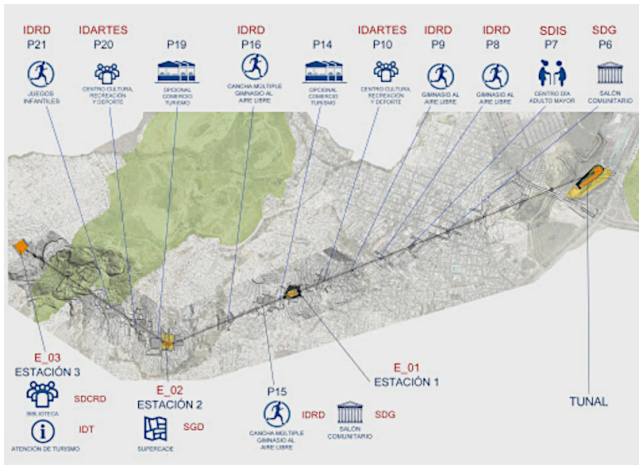
- Happiness Center (CEFE Tunal): It will have swimming pools, a sports center, gymnasium, learning and music rooms, cinema auditorium, restaurants, and shops.

At present, several projects are still under construction or even remain unfinished projects (Fig. 8).

These complements make Transmicable an innovative means of public transportation in both urban development and social growth. The system is functional, and most of the time it is being well-executed, it was recognized in March 2019 as a comprehensive mobility solution by the International Finance Corporation, an international development institution.

Figure 8

Transmicable related projects (Moyano et al., 2018).



Students from the Faculty of Engineering of the Catholic University of Colombia conducted a research project entitled "Evaluation of the Social Impacts Projected for the Transmicable around the Juan Pablo II Station in Ciudad Bolivar" (Moyano et al., 2018). They considered two variables: travel time and quality of life, depending on the former. In the document there is a great variety of information; from a summarized analysis of Bogota as a growing city, focusing on the locality of Ciudad Bolivar to the organization of data that allows knowing several characteristics of the aerial cable, implementation, types, costs, and others.

The students, who completed a thesis of more than 100 pages, provide figures and conclusions, thus; the direct benefits are: Decrease in travel times, Decrease in the cost of transportation, Public Investment, and Improvement in mobility. Also and clarifying that the difference between direct and indirect benefits, for the authors, is that the indirect benefits refer to those that are not part of the same group of services or goods in this case transportation, then they are: Decrease in insecurity, Variation in the economic activity of the community, Generation of employment, Strengthening of cultural activities of the community, Generation of sense of belonging, Valuation of real estate. Strengthening of public spaces, integration of areas, reduction of accidents, accessibility, and social inclusion. All these items have their respective analysis, in some of them a comparison is made, the quality of life as appropriate with and without the project, making use of tables, graphs, and references.

They concluded that for the most part the impact is positive and generates a benefit for the community. Where the result is not so general and has several approaches supported by its methodology. Thus using at the beginning a data collection continuing with, its identification and

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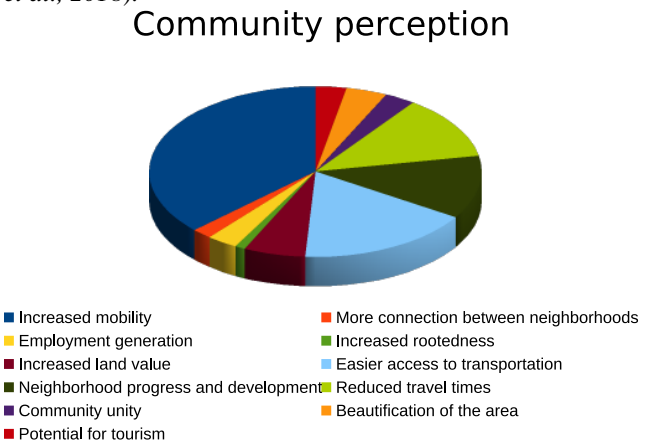
Figure 9

Evaluation of the social impacts projected for Transmicable around the Juan Pablo II station in Ciudad Bolivar (Moyano et al., 2018).



collection by ad-hoc methodology, quantitative social evaluation, and finally data aggregation (Fig. 9).

The journalist Ana Cristina Ayala in her report entitled *The lives that changed the Transmicable* published in the magazine Semana on its official website, on July 15, 2019 (Ayala, 2019). It exposes a series of dialogues, which in addition to generating some sentimentality, caused by the economic situation of these people, also refer to how the operation of Transmicable impacts. a solution of employment generated by tourism, comfort for people with disabilities, and easy access to local businesses, are the cases that are read in the magazine Semana, however, it is not accurate to generalize the impact of the means of transport with the cases of the report, but if they can be considered.

The people of Ciudad Bolivar with whom the journalist had contacted express great approval and not only that, they expect the completion of the facilities such as the viewpoint to undertake personal projects, all to improve their quality of life. Without having figures and/or percentages, and considering the context, this kind of information is considered important, since it provides data from the experience of the community.

Transmicable began to operate on December 27, 2018, with the first rides at no cost for the community to get to know the new aerial cable in the locality of Ciudad Bolivar. Upon completing one-year Transmilenio S.A. announces that it has mobilized more than 7 million passengers throughout this year.

These same numbers, i.e. with Transmicable operating for one year, almost 63% of the workers, i.e. 185 workers, live in areas surrounding the localities of Ciudad Bolívar and Tunjuelito, which Transmilenio SA describes as a *benefit for the surrounding areas*. As for the social sense that has been given to the work, more than 320 activities were carried out with the objective of the good use of the system and the sense of belonging. For the physical well-being of the inhabitants and the care of the environment, it is known that with the service operating for one year, 756 tons of CO2 are reduced annually. It should be noted that at that time the Supercade had not yet been built, and several facilities were under construction.

The implementation of the system has been positive in many aspects, such as its good execution day by day, reducing routes, and taking care of the environment. It is also clear that the people who use the means of transport are a vital part when talking about quality, precisely because they use it daily, frequently or live in nearby areas, and they know what problems were dealt with before its operation, thus being able to determine which problems they consider have decreased since Transmicable and the equipment began to operate.

Knowing and sharing this idea, it is considered important to know and/or understand how it improved the lives of the people who developed around the work.

This transportation system since its projection was considered one of the most innovative of the city, since always to find solutions in mobility and other related issues, the mayor's office and the different institutions of urban planning considered appropriate the articulated bus system (Transmilenio), thus making trunk, after trunk, with 9 portals and 138 stations distributed throughout the city. It can be said that it is the basis of public transportation in the capital, mobilizing approximately 2560000 passengers per day, according to global BRT data. However, Transmilenio has large percentages of disapproval by the people of Bogota.

But what is the relationship between Transmicable and Transmilenio? The aerial cable system serves as a power supply for Transmilenio, so we are talking about an innovative means of transport that works very well for citizens and another means that comes with many failures and nonconformity. Nevertheless, we are talking about the reduction of problems in the lives of the inhabitants of the locality, and taking into account that many of them use Transmilenio to get to their work, or place of study in other areas of the city, the reduction of time and money improved their quality of life. This is why it cannot be said that the mobility problem is over for the inhabitants of Ciudad Bolivar, the problem of public transportation has been reduced. To get to the portal of Tunal, each passenger spends approximately 13 minutes, and not an hour as it happened before, but still has to wait for the trunk service which is not entirely efficient, clarifying that not all citizens who use Transmicable also make use of the articulated bus system.

Transmilenio S.A. gives in its balance of operation of the first quarter of Transmilenio, announces that there is

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a savings of $8.8 billion pesos for users talking about the reduction of travel times.

This last information shows the way in which *the reduction of problems* related to the impact of Transmicable is meant to be understood. Taking into account the face-to-face surveys with structured format conducted by the Urban Development Institute on July 3, 4, 5, 6, and 7, 2015 the first survey and the second one on March 4, 5, and 6, 2019 with the objective of verifying, evaluating and observing the satisfaction of the inhabitants and merchants about the Ciudad Bolivar Transmicable project.

Regarding the knowledge and perception of the project, they were asked about the information pertinent to the project that they had received from the IDU, from which it was obtained that before the work 40% received while the remaining 60% did not have information on the project, and after the work was done the data changed, so 82% now received information on the project and 18% had not yet been provided with information on the work by the IDU directly.

Regarding the condition of the environment, the following figures were presented. Before the project the surveys showed that out of 301 surveys 14% considered it good, 23% fair and 62% totally bad. With the project completed and underway, the following results were obtained. Of the same sample (301 people) 59% considered it good, 32% fair and 8% bad. In percentage terms, the increase in the good perception of the environmental condition was 45%, which helps to verify the positive impact on environmental issues that have improved since the implementation of the project.

Transmicable Impact

If we consider the impact of the transportation system in a timeline, we have the quality of life of the inhabitants before, during, and after (nowadays) the system was built and started to operate in Ciudad Bolivar. The impact is given by the improvement, the comparison between before and after. Taking into account all the aspects that surround the work and the complementary works or equipment that currently operate or are under construction. Such as mobility, comfort, safety, security, environment, culture, and others.

With previous knowledge of the problems that the area of the locality has and/or had, before December 2018, the date when Transmicable began to operate and instant where people began to notice the reduction in some of the problems with which they lived daily.

The conformity of the users and inhabitants of the area goes hand in hand with the impact of the Transmicable since the service was born from the need of the people, then since its projection, the transportation system had to be, by and for the community that lived in the upper neighborhoods, or any person that wanted to arrive and/or leave from there. That is why it was considered that the most important thing when talking about impact, is the opinion of the users, known through surveys and similar methods, without leaving aside, the studies and figures that clearly show the decrease of negative aspects.

Public opinion is something that is reached through many ways, one of them is the survey, and concerning the Transmicable, public entities have been the ones who have been in charge of this to corroborate the results of their work.

Then the face-to-face surveys with structured format conducted by the Urban Development Institute on July 3, 4, 5, 6, and 7, 2015 the first survey and the second one on March 4, 5, and 6, 2019 to verify, evaluate, and observing the satisfaction of the inhabitants and merchants about the Transmicable project of Ciudad Bolivar.

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Another aspect that was surveyed is the landscape environment, which is taken advantage of by the visuality provided by the locality due to the height of its neighborhoods, in this aspect we have the following figures. During the construction stage, those surveyed considered that the visual environment was also quite good, with 51% considering it good, 38% fair and 10% poor. With the project under execution, 65% considered it good, 30% fair and 4% bad, although with the operation of the service this aspect improved by 14% concerning the previous perception of those surveyed.

Another item that was used in these surveys was the image of the sector, the image of the locality, which from the beginning was considered a good attribute of the locality by a good part of the respondents: 49% consider it good, 38% regular, and 13% bad. With the implementation of the project, an improvement of 19% is evidenced, resulting in 68% considering it good, 27% fair, and only 3% bad.

Another aspect evaluated was the public space of the locality, which during the construction process gave the following results: 34% considered it good, 46% regular, and

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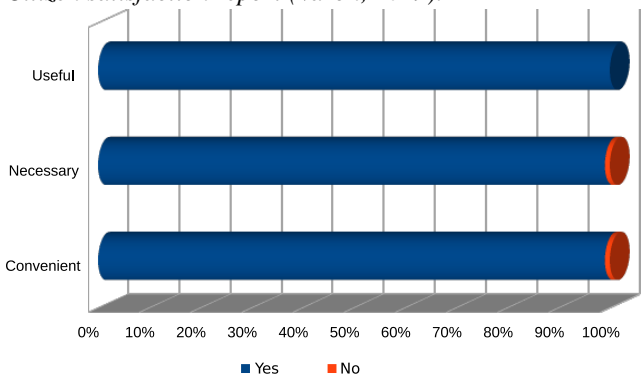
Figure 10

Citizen satisfaction report (Varón, 2019).



19% bad, but with the service, the perception of this aspect improved by 22%, resulting in the following percentages: 56% considered it good, 40% regular and 3% bad.

One of the two aspects that are considered the most important for the people of the community is security, which registered the following figures during the planning of the project: 20% considered it to be good, 43% considered it to be bad, and 8% considered it to be good: 20% consider it good, 43% regular, and 36% bad, even so with the implementation of the service the perception of this aspect is not that it has improved much, exactly 3%, since it is one of the strongest and most relevant problems that for a long time, unfortunately, has plagued this locality resulting in the following figures: 23% consider it good, 44% regular and 32% bad, this reflects the need of the people in this social area.

The other important aspect, which is considered one of the main objectives of the Transmicable, is mobility, which before the project had the following percentage data: only 16% considered it good, 43% regular, and 40% bad. However, with the implementation of the integral Transmicable service, the perception of mobility in the sector improved by 35%, resulting in the following survey results: 51% now consider it good, 43% regular and 6% bad.

After having evaluated some of the aspects that were considered relevant in these surveys, the next step is to observe the satisfaction of the citizens with the integral Transmicable project using the following survey. What is your level of satisfaction with this project? Of which 92% of the 301 respondents consider themselves satisfied, 6% satisfied and only 2% dissatisfied. Regarding the valuation of the local properties, the following results were obtained: 97% consider that they have increased in value, 2% that they have remained the same, and 1% that they will decrease in value over time (Fig. 10).

At the end of the questionnaire a space was set aside for suggestions, negative aspects, and positive aspects that users would like to leave, below will be some of these:

Positive comments

- Improved image
- Good service
- Good project
- Much improved mobility

Suggestions

- Place banking entities in the sector
- Improve security in the sector
- Improve garbage collection
- More transportation routes
- Lack of parking in the sector
- Place more projects like this in the city
- Invasion of public space
- Improve public lighting
- Think about the elderly
- Purchase missing plots of land
- Campaigns to improve the image of the sector
- Install the escalator as planned
- Lack of culture and more visibility of the project
- More incentive for tourism
- Do not place bollards
- Transportation subsidy for students
- There is no control over the sector's JACs

Negative remarks

- Improve road signage
- Maintenance of roads
- Fare collection between stations
- Fulfill the schedule provided by the Transmicable.
- Have not complied with the soccer field, CADE, and library.
- Very slow system

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- Clear information on transfer and payment.
- Comply with the projects planned for the neighborhood.
- Noise is very annoying
- The system needs to be more integrated with the trunk lines.
- They did not develop the work as they said they would
- Interruptions in light service
- The project displaced them from the sector
- The Transmicable system is very slow
- Adapt crosswalks
- Affected commerce due to the works
- Fulfill what they promised about the project
- They left a sewer uncovered
- The finishes of the project need to be finished.
- Lack of speed bumps
- Searches in the system are uncomfortable.
- More coordination on the feeder routes
- Improve public space
- Improve connectivity of trunk lines.
- Improve mobility in the sector.
- Lighting at Manitas station
- Improve fares as it is a popular sector
- Very expensive
- Very bad transportation
- Paving streets in the sector
- Transmicable makes the doors of the houses vibrate.
- The turnstile is cumbersome
- Lack of surveillance cameras

All these percentages give us the clear idea that most of the inhabitants tend to consider the arrival and operation of the system as good, the before and after in general has a big difference. However, we have the list of negative observations, which is more extensive than the positive observations, and has a large number, because it can be seen more specified, this shows that although the percentage of conformity is high, the commitment of public and private entities that are responsible for the work and the surrounding works is still needed.

In this way, we can conclude that, if we base ourselves on the general opinion of the people to speak of a reduction of problems, they did have a reduction, and we can speak specifically of:

- Mobility: Reduction of travel times, users take almost an hour less, trips of three hours were reduced to two, for example.
- Inclusion and culture: easy access to peripheral areas, and government presence, previously the areas were excluded due to difficult access and government neglect (lack of institutions and/or points of care).
- Improvement of spaces: conformity of the people living in the sector, where before it was not considered a good place to live.
- Economy: promotes local businesses, reduces transportation costs for families.

This transport system since its projection was considered one of the most innovative in the city, since always to find solutions in mobility and other related issues, the mayor's office and the different institutions of urban planning considered appropriate the articulated bus system (Transmilenio), thus making trunk, after trunk, with 9 portals and 138 stations distributed throughout the city. It can be said that it is the basis of public transportation in the capital, mobilizing approximately 2560000 passengers per day, according to global BRT data. However, Transmilenio has large percentages of disapproval by the people of Bogota. But what is the relationship between Transmicable and Transmilenio? The aerial cable system serves as a power supply for Transmilenio, so we are talking about an innovative means of transport that works very well for citizens and another means that comes with many failures and nonconformity. Nevertheless, we are talking about the reduction of problems in the lives of the inhabitants of the locality, and taking into account that many of them use Transmilenio to get to their work, or place of study in other areas of the city, the reduction of time and money improved their quality of life. This is why it cannot be said that the problem of mobility is over for the inhabitants of Ciudad Bolivar, the problem of public transportation was reduced. This is a concrete fact that deals with the reduction of a problem (mobility and/or public transportation). To get to the portal of Tunal each passenger spends approximately 13 minutes, and not an hour as it happened before, but still has to wait for the trunk service which is not entirely efficient, clarifying that not all citizens who use Transmicable also make use of the articulated bus system.

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The figures and the collection in conjunction with the organization of the information allow us to point out what other benefits the transport system has brought. This can be specified by themes (environment, technology, economy, etc.). The care of the environment is linked to the welfare of people and the environment where they live, that is why it can be considered a necessity to take care of the environment, in this case by implementing public transport services such as Transmicable. It is a means that does not use fossil fuels and therefore cares for air quality, uses solar panels, reducing gas emissions. Being one of the works recognized so that the urban development institute received certification for complying with environmental construction standards.

Before the construction of the aerial cable, the way to travel to more central areas or to the Tunal portal was by means of buses, vehicles that expose the user to air pollutants, and because they use fossil fuels they cause many environmental problems in the long term. Therefore, the environmental benefit brought by the Transmirable is important, it reduces pollution in the area, and therefore, the health problems it can cause in the long term. And it takes care of the ecosystem, which is a place to preserve life. However, the environmental problem in Bogota is a problem that is constantly increasing due to the lack of the use of technologies such as the TransMicable, which only reduces to a very low degree the environmental problems faced by the capital and its inhabitants. This means that even so, users continue to be exposed to pollution.

The complementary works that were built and those that are in the process of being built also arose from the need of the inhabitants to have quality public common areas that would generate belonging and security. And these elements are the ones that are contemplated as "Urban Renewal" in the whole project involving Transmicable. The fact that this area of the locality now has parks and attention buildings such as the CADE, makes a difference for populations such as young people who have more recreational spaces, thus decreasing the possibility of their involvement in different social conflicts to which they are very vulnerable, such as gangs, illegal substances, etc.

The issue of security in the locality is complex and even with the system in operation, according to surveys conducted by the IDU, it did not have a very noticeable improvement, however, the mayor's office clarified that it is a system that provides security to users at all times and is constantly monitored by security cameras, something that did not happen before when people used buses and other public transport (Fig. 11).

The quality of life is closely linked to the economic level of families, and the entry into operation of the transport system-generated jobs. In the initial phase, according to the company in charge (Transmilenio S.A.), 192 people were hired, 75% of the citizens living in the locality. And in

Figure 11

Transmicable related projects (Moyano et al., 2018).

this same context, within the planning of spaces, there are commercial areas that would generate income for merchants, together with the viewpoint that is under construction, tourism would also generate income, having an economic sustainability, both for people and for the locality. The before and after in this case is quite visible since the development can be denoted, in a certain way Transmicable generated economic stability to a small percentage of families living in the area and can continue to do so at the time of completion of the pending works.

Transmicable has been in operation for approximately two years and has improved the quality of life of the local inhabitants by shortening routes, improving mobility, reducing the marginalization of the area by making it more accessible and with the necessary state presence, generating a sense of belonging for the inhabitants by making it pleasant, reducing pollution levels, protecting both public health and the ecosystem, cultural projects address the social conflicts that affect the area, providing security and comfort, and generating spaces for economic growth.

Conclusion

In conclusion, the Transmicable is one of the most innovative and inclusive works that have been carried out in the capital, since it was made in a locality of difficult access, where people are mostly poor, although this work has a high rate of conformity, there is also a lot of nonconformity since the inhabitants have denounced that the work was not carried out as promised, In addition, it has certain inconsistencies inside and outside the system (in the surrounding works), such as the lack of maintenance of the system, the lack of security inside the system and the damages that are not fixed in the surrounding works, which is why there are still people who are not satisfied with the system.

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As for the environmental impact, this project is very good because it meets certain requirements that do not harm the environment, in addition to not using fossil fuels such as diesel which reduces gas emissions in the atmosphere, so this project is Eco friendly.

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Review of strategies for input current reconstruction

Revisión de estrategias para reconstrucción de la corriente de entrada

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Understanding the theory of active power factor correction in single-phase regulators can be quite complex for young students. This is even more critical if one considers the diversity of strategies that exist, their combinations, and even the existence of both passive and active strategies. In some way, all these approaches seek to reconstruct the input current signal, but the strategy used may be significantly different in each case. This article aims to present an overview of these techniques that can be used as a starting point for the study and design of equipment.

Keywords: Active correction, harmonic distortion, power factor, signal reconstruction, single-phase rectifiers

Entender la teoría de la corrección activa del factor de potencia en reguladores monofásicos puede ser bastante complejo para jóvenes estudiantes. Esto es aún más critico si se considera la diversidad de estrategias que existen, sus combinaciones, e incluso la existencia de estrategias tanto pasivas como activas. De alguna forma todas estas estrategias buscan reconstruir la señal de corriente de entrada, pero la estrategia utilizada puede ser sensiblemente diferente en cada caso. En este artículo se busca presentar una visión general de estas estrategias que sirva de punto de partida tanto para estudio como para el diseño de equipos.

Palabras clave: Corrección activa, distorsión armónica, factor de potencia, reconstrucción de señal, rectificadores monofásicos

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Introduction

The vast majority of electrical energy generated worldwide corresponds to alternating current (AC), the systems of generation, transmission, and distribution of electrical energy (power system) are designed for this form of current (Liu et al., 2016; Pahlevani et al., 2014). However, the current loads used in the different electrical energy consumption equipment require direct current (DC), largely due to the electronic component that is part of the load (Martínez, 2009b; Martínez et al., 2013). Given the large number of low and medium power devices that require a power supply, their impact on the power system is a major problem (Martínez et al., 2019). These devices obtain their direct current using a rectifier circuit, or AC-DC converter, which takes the energy from the power system and rectifies it (Akther et al., 2019). These circuits are implemented with semiconductor elements such as diodes and thyristors in controlled and uncontrolled schemes, which ensure that the electric current flows through the load always in the same direction (Martínez & Jacinto, 2013). However, with these schemes, the current drained from the power network behaves as pulses due to the conduction intervals of the rectifier circuits (Martínez, 2003). The rectifier circuits turn out to have a non-linear behavior that changes the waveform of the current signal in the power network (and of the voltage as a consequence of voltage drops), which is a major problem since this is done in an enormous amount of medium and low power equipment simultaneously. These electrical current peaks lead to a lot of problems for the power system, among which we can mention: high harmonic content in the electrical current, low efficiency of the rectifier circuit as a consequence of the high RMS value of its input current, low power factor (PF) as a consequence of the distorted current, and losses in power equipment designed to operate with low-frequency signals (Martínez & Gómez, 2004).

Due to the large amount of this equipment connected to the grid, and the cumulative consequences for the power system, several agencies have considered limits for the injection of harmonics, intending to guarantee the quality of the electrical power (Martínez, 2001). Among these standards and norms are the IEC (International Electrotechnical Commission) 61000-3-2 (electromagnetic compatibility, applied in Europe), EN 50006, VDE Standard 0160 for converters, and the ANSI/IEEE 519-1992 Standard for compensation in power converters, applied in the United States (Ochoa et al., 2017). To comply with these recommendations, numerous schemes for the reconstruction of the input current signal have been proposed in the specialized literature (Martínez & Gómez, 2012). According to how this process is performed, these correctors can be classified into passive, active, and hybrid schemes (Jauch & Biela, 2016). Passive schemes usually do not provide a complete solution to the problem and have cost and efficiency problems. On the other hand, active methods pose complexity and reliability problems, leaving hybrid schemes as the ideal configuration with the best advantages (Martínez, 2009a; Martínez & Gómez, 2007; Riaño et al., 2012; Vásquez & Martínez, 2011).

In this paper we seek to present in a summarized form, by way of documentation, the different existing schemes for power factor correction in the rectification stage of medium and low power equipment (single-phase equipment below 16 A). As stated in the literature, these schemes have been separated into three groups according to the behavior of the elements that perform the correction: passive methods, active methods, and hybrid methods. For each case, a description of the scheme, its general circuit, and its behavior as a correction scheme is presented. The structure of the rest of the document is as follows, in the next section a methodological overview is presented with the classification of the analyzed methods. The third section details each of the methods and their principle of operation. Finally, the fourth section presents our conclusions.

Methodological Overview

Given the high impact and its wide use, this discussion focuses on the correction schemes of the current signal at the input of single-phase rectifier circuits, in medium and low power applications (de Souza et al., 2019). Traditionally the problem is addressed in two ways, passively by installing filters, and actively by power converters that implement some control scheme on semiconductor devices operating at a frequency much higher than the frequency of the power network (Monteiro et al., 2019). Considering the advantages and disadvantages of each case, it is possible to include a third classification in which hybrid schemes are implemented with the support of both filters and high-frequency switched elements (Fig. 1). In any case, the objective is to return the current signal to its sinusoidal form and in phase with the voltage signal, so that the power factor returns to the nominal value of one. This is why these schemes are also known as power factor correctors (PFC) or resistive emulators.

Due to the high generation of current harmonics produced by single-phase rectifier circuits, their extended use in the power system can place the system at an operating point that exceeds international standards. Among the problems that this entails is a decrease in the quality of the power supplied, negative effects on system equipment such as harmonic losses in all equipment, reduction in installed capacity, current peaks in power capacitors, and consequently, oversizing of equipment, particularly power transformers. For reference, Tables 1 and 2 show the harmonic limits for IEC 61000-3-2 and IEEE 519-1992 standards.

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Figure 1

Classification of methodologies for current reconstruction according to the control scheme (Kazem, 2007).

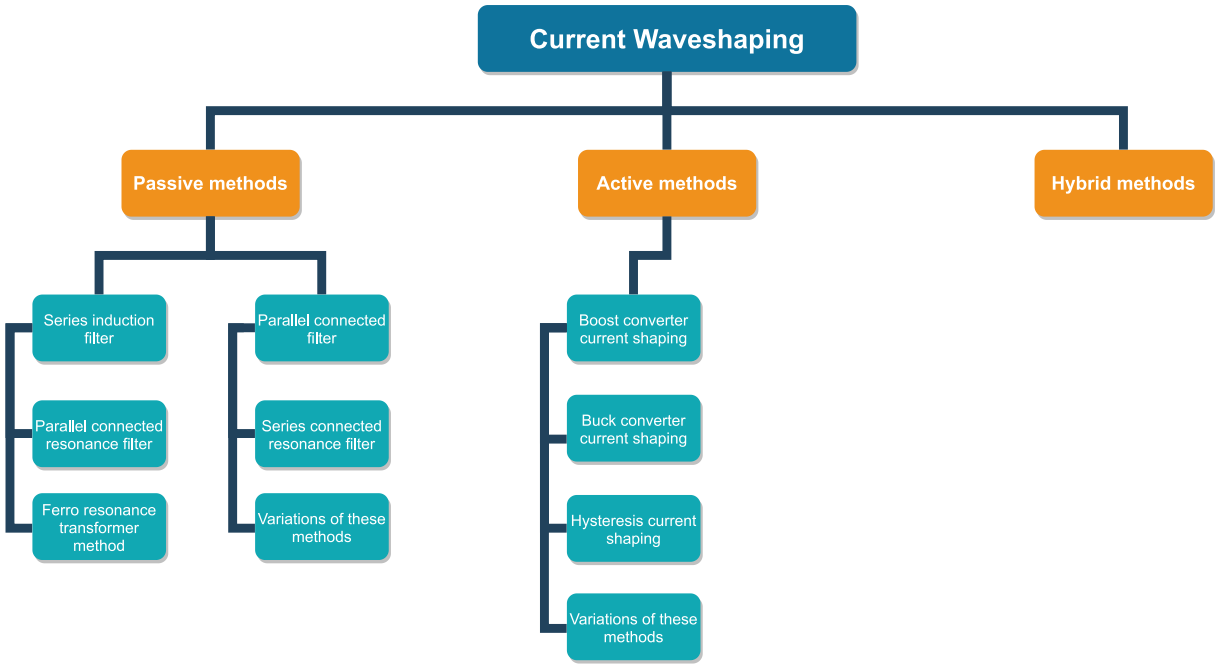

Table 1

Harmonic current limits allowed by IEC 61000-3-2 for class A equipment (balanced three-phase and single-phase equipment not included in other classes).

Harmonic order h	Maximum allowable harmonic current [A]
Odd harmonics	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
$15 \leqslant h \leqslant 39$	$2.25/h$
Even harmonics	
2	1.08
4	0.43
6	0.30
$8 \leqslant h \leqslant 40$	$1.84/h$

As mentioned, the generation of electrical energy is done by transforming another energy form into electrical machines using the rotational movement of electric charge in a magnetic field. This produces electrical signals of periodical behavior, specifically of sinusoidal type. The current signal is distorted because of the non-linear loads that produce current peaks, but it is still a periodical signal. This current $i(t)$ is a non-sinusoidal periodical signal that can be analyzed by decomposing its fundamental $i_1(t)$ (component at the mains frequency, 50 Hz or 60 Hz depending on the country) and its h harmonic components $i_h(t)$ (frequencies multiplied by the fundamental). This is written as follows:

$$i(t) = i_1(t) + \sum_{h=2}^{\infty} i_h(t) \tag{1}$$

The harmonic distortion of a waveform represents the harmonic content of that signal. The amount of distortion in a voltage or current waveform is quantified by an index called total harmonic distortion (THD). This index is defined for mains voltages and currents as shown in Eqs. 2 and 3. In these equations, V_1 and I_1 correspond to the fundamental voltage and current components respectively, and V_h and I_h the h-harmonics, all in RMS terms.

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \tag{2}$$

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Table 2

Harmonic current limits $\left(\frac{I_h}{I_1}\%\right)$ *established by IEEE 519-1992 for the non-linear load connected to the utility grid at the point of connection.* I_{SC} *is the maximum short circuit current, and* I_1 *is the maximum fundamental current. Even harmonics are limited to 25% of the limits for odd harmonics.*

I_{sc}/I_1	Order of odd harmonics h					THD [%]
	$h<11$	$11<h<17$	$17<h<23$	$23<h<35$	$35<h$	
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 - 50	7.0	3.5	2.5	1.0	0.5	8.0
50 - 100	10.0	4.5	4.0	1.5	0.7	12.0
100 - 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \tag{3}$$

Under these conditions, the power factor (PF) is defined as the product of the displacement power factor (DPF) and the ratio $\frac{I_1}{I_S}$ (Eq. 4). In this equation, DPF corresponds to $cos\varphi$, where φ is the phase angle between voltage and current. As can be seen, the power factor is closely linked to the harmonic distortion, the higher the harmonic distortion, the higher the total current I_S concerning its fundamental component I_1 (since the rest are harmonics), so that the power factor decreases. Therefore, the presence of harmonics in the current has a very negative effect on the efficiency with which the equipment provides power to the network, and it is a very important aspect to control, not only for safety but also for effectiveness.

$$PF = \frac{P}{S} = \frac{I_1}{I_S} \times DPF \tag{4}$$

Strategies for the Reconstruction of the Current Signal

Passive methods

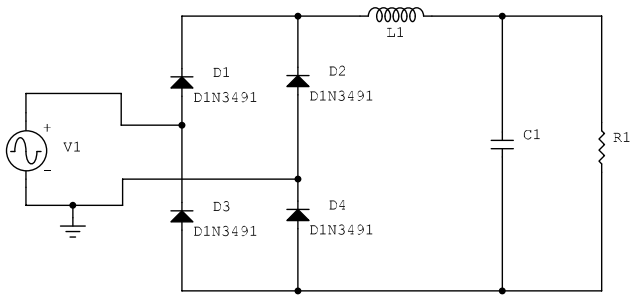
These methods use passive elements (inductors and capacitors) to try to improve the input current waveform and therefore provide the circuit with at most a gain of one. This strategy involves a series supply reactor that functions as a tuned harmonic filter (in series or parallel). The most common methods are the inductive filter, the resonant filter, and the ferroresonant transformer.

Series Induction Filters (SIF)

To attenuate the ripple of a rectified signal, a capacitor is commonly used in parallel with the load of the circuit. Intuitively, it can also be noted that using a series inductance

Figure 2

Full wave rectifier with inductive filter on the DC side.



the ripple value in the load can be reduced (low-pass filter). By connecting a coil with a capacitor in an L-mount, it is possible to take advantage of each of these filters and obtain excellent results in both low and high power consumption. This inductor can be placed before (AC side) or after the bridge rectifier (DC side), then place the inductor in series with the output of the diode bridge, and analyze approximately how the output signal behaves (Fig. 2).

A full-bridge rectified signal can be expressed in the Fourier series. In the expression found there is a constant term and a series of terms of alternating characteristics at the frequency of 2ω, 4ω, 6ω,.... A coil placed in series with the load (in this case with the equivalent impedance of the capacitor in parallel with the load) behaves as a low-pass filter. In this way, the continuous signal will pass through the inductor (this being short for it), and of the time-varying signals, the 2ω frequency signal will be the least attenuated. Accordingly, in the following analysis, the other components of frequencies higher than 2ω are neglected (note that the

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4ω frequency harmonic is in amplitude only 20% of the amplitude of the 2ω component).

The impedances of the circuit elements are as follows based on this approximation of the signal incident on the filter:

$$\text{Capacitor} \rightarrow \frac{1}{2j\omega C} \tag{5}$$

$$\text{Inductor} \rightarrow 2j\omega L \tag{6}$$

In the circuit we have a divider formed by X_L and X_C in parallel with the load R. Depending on the incident ripple v_{ri}, the output ripple v_r will be:

$$v_r(t) = v_{ri}(t)\frac{X_L \,||\, R}{X_L + (X_C \,||\, R)} \tag{7}$$

For the capacitor to operate effectively, that is, for the capacitor to be able to supply the load, it is necessary to have to:

$$\left(X_L \,||\, R\right) << R \tag{8}$$

In other words:

$$\frac{1}{2\omega C} << R \;\Rightarrow\; C >> \frac{1}{2\omega R} \tag{9}$$

And, for this case, the expression for the output ripple is:

$$v_r \approx v_{ri}\frac{X_C}{X_L + X_C} \tag{10}$$

Since a small ripple is desired, the value to be chosen for X_L must be large compared to X_C, i.e:

$$2L\omega >> \frac{1}{2\omega C} \;\Rightarrow\; L >> \frac{1}{4\omega^2 C} \tag{11}$$

Which produces a ripple of:

$$v_r \approx v_{ri}\frac{X_C}{X_L} \tag{12}$$

The ripple factor is defined as:

$$r = \frac{V_{r(eff)}}{V_{med}} \tag{13}$$

Where:

$$V_{r(eff)} = \frac{V_{r(pico)}}{\sqrt{2}} = \frac{4V_p}{3\pi\sqrt{2}}\frac{X_C}{X_L} \tag{14}$$

$$\text{and } V_{med} = \frac{2V_p}{\pi} \tag{15}$$

Therefore, the ripple factor is defined as:

$$r = \frac{\sqrt{2}}{3}\frac{X_C}{X_L} = \frac{\sqrt{2}}{3}\frac{1}{4\omega^2 LC} \tag{16}$$

At 60 Hz, and expressing the values of C in μ-Farads and L in Henries, we have that:

$$r = \frac{0.83}{LC} \tag{17}$$

The configuration shown in Fig. 2 can operate in a continuous or discontinuous mode according to the current conduction in the diode bridge. The expressions stated above are valid as long as they do not imply a current reversal in the coil (which diodes do not allow). This inversion will occur when the peak value of the ripple current $\left(\sqrt{2}I_{r(eff)}\right)$ becomes equal to the average current $\left(I_{med} = \frac{V_{med}}{R}\right)$. To avoid this current reversal, it must be kept in mind that:

$$I_{med} \geq \sqrt{2}I_{r(eff)} \tag{18}$$

Where:

$$I_{r(eff)} = \frac{V_{r(eff)}}{X_C} = \frac{rV_{med}}{X_C} = \frac{\sqrt{2}}{3}\frac{V_{med}}{X_L} \tag{19}$$

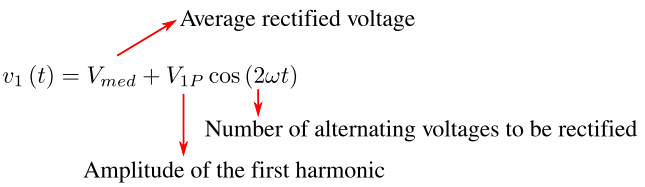
And replacing this in condition (18):

$$\frac{V_{med}}{R} \geq \frac{2}{3}\frac{V_{med}}{X_L} \;\Rightarrow\; X_L \geq \frac{2R}{3} \tag{20}$$

This is the value known as critical inductance, which defines the operating mode of the circuit. Since this analysis is approximate, in practice this value should be increased by at least 25% to ensure continuous mode operation.

At low current consumption levels, the above characteristic is not fulfilled, and the L-filter behaves as a capacitive filter (Fig. 3). Above a certain value of consumption I_0 the L-filter operates normally and the established results can be applied. It should be noted that the output resistance R_{output} for power consumption greater than I_0 is equal to the sum of the coil resistance and the rectifier resistance. The equivalent model of this type of filtering is shown in Fig. 4.

This approximation of the first harmonic tends to overestimate the continuous conduction limit and the value of the critical inductance must be corrected. Let us now observe the effect on the PF. The voltage applied to the circuit is as follows:



$$v_1(t) = \frac{2V_p}{\pi} - \frac{4V_p}{3\pi}\cos(2\omega t) \tag{21}$$

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Figure 3

Control curve for the inductive filter.

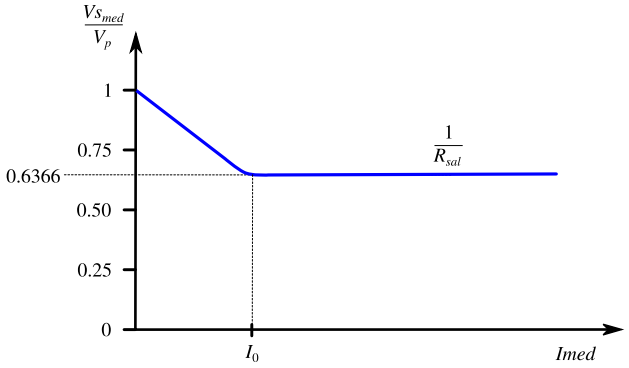
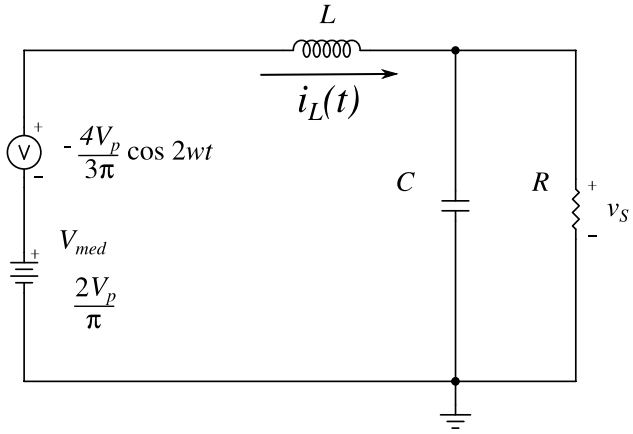


Figure 4

Equivalent model of the inductive filter on DC side.



In continuous conduction we have:

$$v_1(t) = \frac{2V_p}{\pi} - \frac{4V_p}{3\pi}\cos(2\omega t) = L\frac{di_L(t)}{dt} + i_L(t)\,[R \parallel C] \quad (22)$$

$$v_1(t) = L\frac{di_L(t)}{dt} + i_L(t)\left[\frac{R}{1+\omega^2R^2C^2} + \frac{\omega R^2 C}{j(1+\omega^2R^2C^2)}\right] \quad (23)$$

Taking:

$$R' = \frac{R}{1+\omega^2R^2C^2} \quad (24)$$

It is concluded that:

$$v_1(t) = \frac{2V_p}{\pi} - \frac{4V_p}{3\pi}\cos(2\omega t) = L\frac{di_L(t)}{dt} + R'i_L(t) + E \quad (25)$$

Where E would represent the complex part of this voltage. Solving this equation leads easily to:

$$i_L(t) = \frac{\frac{2V_p}{\pi} - E}{R'} + \frac{\frac{4V_p}{\pi}}{3\sqrt{R'^2 + L^2 4\omega^2}}\cos\left(2\omega t - \arctan\frac{2\omega L}{R'}\right) \quad (26)$$

To simplify the expressions and facilitate their analysis, the following parameter will be used:

$$K = \frac{2L}{R'T} \quad (27)$$

This parameter K is called the conduction parameter (in reality this parameter is usually indicated as a function of the load resistance R and not as a function of R', however, due to the value assigned to R', this change does not affect the results that will be reached). From this, the circuit current is:

$$i_L(t) = \frac{\frac{2V_p}{\pi} - E}{R'} + \frac{\frac{4V_p}{\pi}\cos\left(2\omega t - \arctan\frac{2\omega L}{R'}\right)}{3R'\sqrt{1+4K^2\pi^2}} \quad (28)$$

From this statement it can be deduced:

- The average value of the current:

$$I_{med} = \frac{\frac{2V_p}{\pi} - E}{R'} \quad (29)$$

- The r.m.s. value of the current:

$$I_{L(eff)} = \sqrt{\left[\frac{\frac{2V_p}{\pi} - E}{R'}\right]^2 + \left[\frac{\sqrt{2}\frac{2V_p}{\pi}}{3R'\sqrt{1+4K^2\pi^2}}\right]^2} \quad (30)$$

- The current form factor (r.m.s. current value of $i_L(t)$ referred to I_{med}):

$$FF = \frac{I_{L(eff)}}{I_{med}} = \sqrt{1 + \frac{\left[\frac{\sqrt{2}\frac{2V_p}{\pi}}{3R'\sqrt{1+4K^2\pi^2}}\right]^2}{\left[\frac{\frac{2V_p}{\pi} - E}{R'}\right]^2}} \quad (31)$$

Now, the active power at the output is equal to:

$$\begin{aligned} P &= \frac{1}{T}\int_{-T/2}^{T/2} v_1(t)\, i_L(t)\, dt \\ &= \frac{1}{T}\int_{-T/2}^{T/2}\left(R' i_L(t)^2 + L\, i_L(t)\frac{di_L(t)}{dt} + E\, i_L(t)\right)dt \end{aligned} \quad (32)$$

$$P = E\, I_{med} + R' I_{L(eff)}^2 \quad (33)$$

Where:

- $E\, I_{med}$ is the useful term corresponding to the power transformed by the load.

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- $R' I^2_{L(eff)}$ is the term corresponding to the Joule losses in the load and in the filter inductance connected in series with it.

For good load performance, the second term needs to be very small compared to the first term. The increase of the current form factor $i_L(t)$ (FF) causes an increase of the various apparent powers, while the active power increases little. Thus, it leads to a reduction of the overall power factor.

Most of the increase in the form factor corresponds, for a given $E \times I_{med}$ value, to an increase in the ripple currents and Joule current losses in the load, in the semiconductors, in the secondary and primary windings of the transformer, and the power supply line. To seek a low ripple in the rectified current, and therefore a high PF value, the value of the conduction parameter K must be increased.

By increasing the value of this conduction parameter the current waveform changes to the ideal case of an approximately square current waveform (Fig. 5). In this case, the PF obtained is 0.9, which is the maximum value obtainable with this type of filter.

However, this type of solution has a major problem, the size of the components used. For example, to feed a 2.1 kW inverter at 120 Vdc requires a 228 mH inductor, with a maximum stored energy of 54 Joules to obtain a PF close to 0.9. The size of the inductor is exaggerated, and therefore, so is its cost. Because of this, solution variants have been implemented to avoid these sizes and costs. One of the most commonly used variants is shown in Fig. 6 and consists of adding a capacitor to the secondary of the system power transformer (C_2) which is used to minimize the current wave distortion factor. The inductance L is then placed to minimize current harmonics in the line by decreasing the current wave displacement, and C_1 is calculated so that the rectified voltage has no significant ripple.

For analysis and testing purposes, this circuit was simulated in SPICE 3 (Simulation Program with Integrated Circuit Emphasis of the University of California, Berkeley) (Nagel & McAndrew, 2018; Sellers et al., 2018)for the following characteristics:

- Type of load: Resistive.
- Power consumed by the load in stationary state: 1920 W.
- DC voltage supplying the load: 120 V.

Using the circuit in Fig. 6, to obtain 120 V DC on the load, for the 3.3 mH inductor, an AC voltage is required at the output of the transformer secondary of:

$$V_p = 170 \text{ V} \tag{34}$$

$$V_{i(eff)} \approx 120.2 \text{ V} \tag{35}$$

And the load has a value of:

$$R = \frac{120^2}{1920} = 7.5\ \Omega \tag{36}$$

Without any type of correction, the diodes would withstand peaks of at least 10 times the nominal current (almost 200 A), so the 1N3491 diode was selected for the rectification, which considerably exceeds these margins.

After a four-cycle transient, stationary behavior of the input current is observed (Fig. 7). Although the current is no longer sinusoidal and resembles somewhat the square behavior identified above, it tries to conduct throughout the network cycle and with little deviation concerning the voltage signal.

Resonant filter

This method is a variant of the use of low-pass filters, in which tuned LC type arrays are used to reduce the amplitude of a certain harmonic, usually those that occur with greater amplitude in the circuit, i.e. third, fifth and seventh harmonic. By surgically eliminating the harmonics that most affect the current waveform, the PF automatically rises as the current waveform now has its fundamental component as the predominant element. These filters are normally located in the power input line, just before the rectifier circuit, and as with the inductive filter analyzed before, it is constructed with an inductor and a capacitor in parallel and can be complemented with inductive filters in series on the AC side (Fig. 8). Since these filters are tuned to a certain frequency, it is possible to eliminate more than one harmonic component, for which it is only necessary to install a new shunt filter for each frequency. Consequently, the only important design criterion to consider is that each filter is tuned to the correct frequency.

Series resonant filter

It could be considered as a general case of the series filter with resonance tuning. In this type of connection, different LC circuits tuned in series with the power supply are used (Fig. 9) (Ji & Wang, 1998; Prasad et al., 1990). If a single LC block is used, then the resonance is only tuned to a single harmonic frequency, but it is common to see it in multi-tuned structures, i.e., with more than one LC block. The example shown in Fig. 9 contains, in addition to the series filter on the AC side, two resonant series blocks, one tuned to the third harmonic (L_{r3} and C_{r3}) and the other tuned for high frequencies (L_{rh} and C_{rh}).

Output filter

Another passive strategy used to reduce the harmonic content in the input current of a rectifier is the use of a filter in the output stage, to increase the conduction time of the current in each half-cycle of the signal. This strategy

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Figure 5

Waveforms in the ideal case of the inductive L-filter.

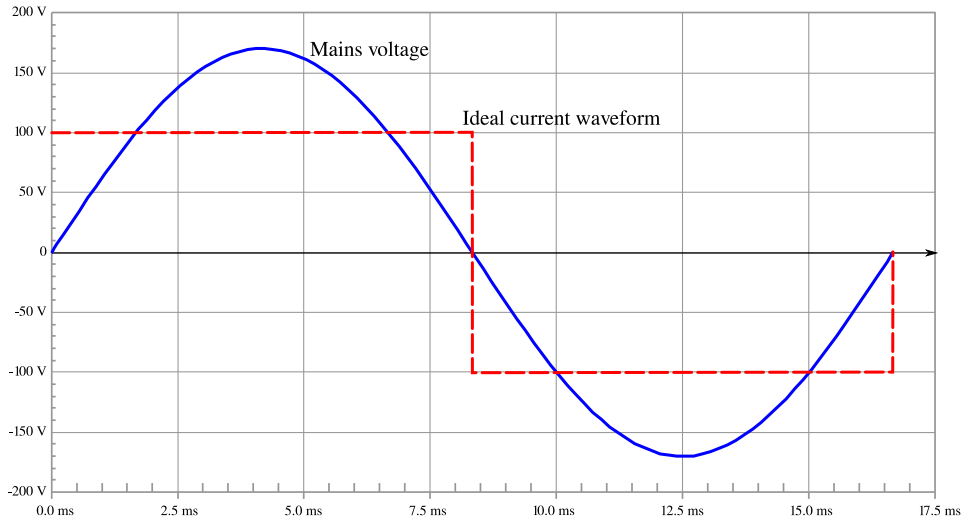
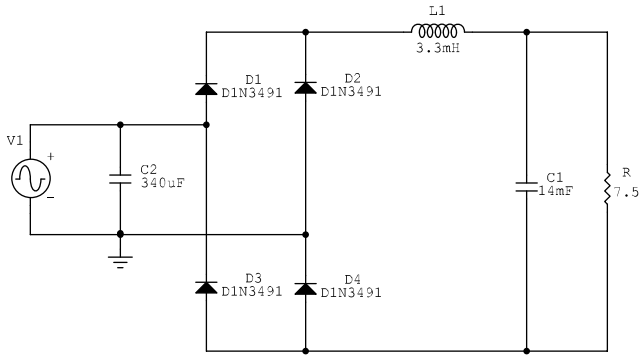


Figure 6

Inductive filter alternative solution.



uses an inductor in series after the rectifier circuit that keeps the current flowing to the load for a longer time (Fig. 10). This inductive element is designed to work with the ripple produced in the rectification, i.e., a low frequency equivalent to twice the mains frequency. Moreover, at this point, there is an average DC that the inductor must handle without saturating. This is why these inductors are known as choke and are designed with special cores or magnetic elements with gaps in their magnetic circuits. This choke tends to be large, so to reduce its volume and cost a small capacitor C_f is used in parallel with the bridge rectifier, which completes the output filter (Redl, 1998). It is also usual in this configuration a diode in series with the choke to prevent current flow from the choke to the capacitor when the rectifier voltage is lower than that stored in the output capacitor C_0 (if the capacitor of the filter L is not used, then the diode is not necessary, and all the filtering falls on the choke and the output capacitor C_0).

Active methods

These strategies use some active-controlled elements such as transistors or thyristors to reconstruct the current signal waveform by continuously tracking the behavior of the voltage signal, which serves as a reference. While most cases (which are the ones detailed in this article) use these active elements in the output stage of the rectifier circuit, there are also active rectification schemes in which the controlled active element is part of the rectifier circuit. Since they are beyond the scope of this research, we do not detail them here, but they can be consulted in the related publications (Martínez, 2003).

Boost converter

The Boost converter is the most used power topology in active PF correction circuits. This topology has several features that make it suitable for this type of application, such as presenting a continuous output current (in circuits operating in continuous operation mode at least) thanks to the choke at the output, whose value can be tracked directly in these elements to make current control, which has been shown to ensure the stability of the converter. In addition, it is an easily controlled booster circuit, which allows any voltage value higher than the input voltage to be obtained at

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Figure 7

Input voltage and current in the inductive filtered circuit.

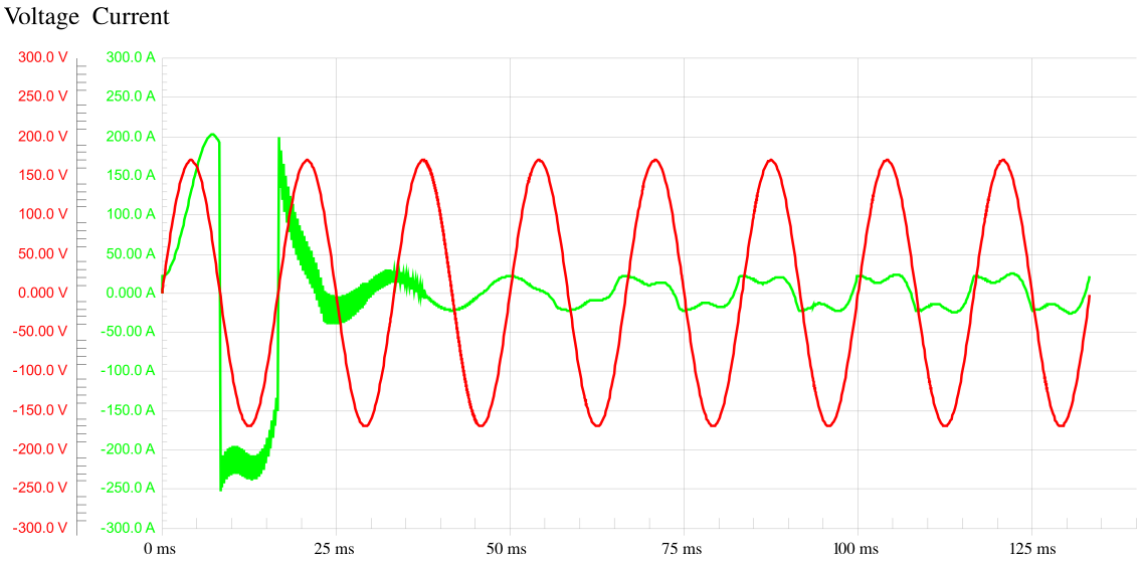


Figure 8

Typical configuration of a parallel resonant filter.

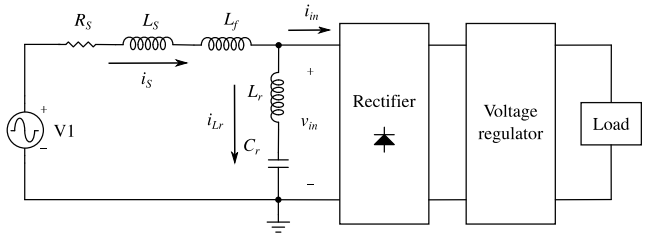
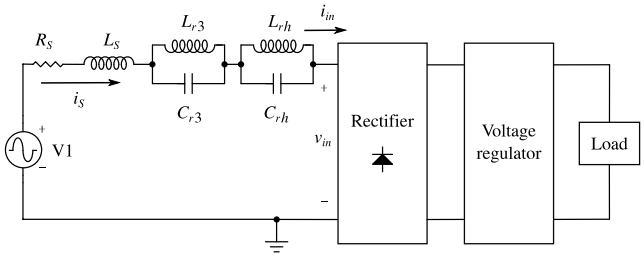


Figure 9

Typical configuration of a series resonant filter.

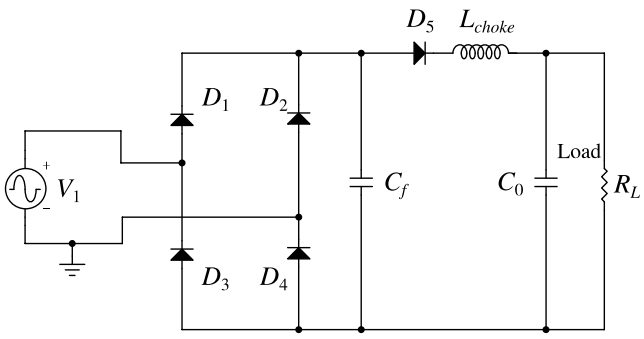


the output. Among the disadvantages, however, is the fact of not having galvanic isolation between input and output, and the restriction of use to low and medium powers.

Like all switched converters, its operating principle is based on the switching of the active switch at a frequency much higher than the mains frequency. When the average duty cycle value is modulated, the average value of the converter input voltage can be controlled. However, if you simultaneously vary this average behavior to follow the instantaneous value of the sinusoidal input voltage signal, then the average current signal drawn by the converter from the mains will also be sinusoidal and in phase with the mains voltage, making the entire converter look like some kind of linear resistance (Fig. 11). The converter is a non-linear circuit, but by operating in this way the network sees it as a linear load, for this reason, these circuits are known as

Figure 10

LC Output filter.



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resistive emulators. The control algorithm used in these converters can be widely different, from traditional PID to neural systems and sliding controls. The important thing in all cases is that the response of the control unit should be much faster than the switching speed of the circuit, which often requires the use of pre-recorded memories with the simulated scheme for any operating condition (something common in fuzzy control schemes).

Other power converters

In cases where a lower output voltage than the input voltage is required, or some wider voltage regulation characteristic, it is normal that the Boost topology is replaced by others such as the Buck converter, Buck-Boost, SEPIC, or CUK (Dacol et al., 2019; Dixit et al., 2019; Eckstein et al., 2019). The latter topologies have the advantage of allowing galvanic isolation, and even continuous output current, something that is not possible without an additional filter with the Buck converter. The control principle in these converters is usually the same as with the Boost converter, two control loops are used, a voltage loop to regulate the output voltage, and a current loop to ensure stability and reconstruction of the current signal. The control loop is of a higher frequency than the switching frequency, while the voltage loop can be slower, close to the frequency of the power grid.

Hybrid methods

The best performance at the lowest cost is achieved by combining active and passive solutions. This type of strategy is called hybrid and has the advantages of the control schemes of the active strategies, and the corresponding advantages of the active elements, such as a resonant operation that reduces the switching powers, and therefore increase the efficiency of the circuits considerably (Jithin & Cherian, 2018; I. Lee, 2015; I.-O. Lee, 2016).

Conclusion

It is clear the need to reduce the harmonic content in single-phase rectifier circuits, its widespread use in everyday equipment makes the injection of harmonics to the network becomes every day a more critical problem. In this article a categorization of the existing methods has been made, however, the variety and quantity are so wide that it is impossible to record them all in a document like this. However, the schemes widely known in the scientific community are recorded, as well as their most important characteristics. This classification emphasizes two schemes, the use of passive filters (which were simulated in a real circuit) and the active strategies based on high-frequency switching of a power converter. The combination of these two basic strategies seems to be the path taken by the most recent research.

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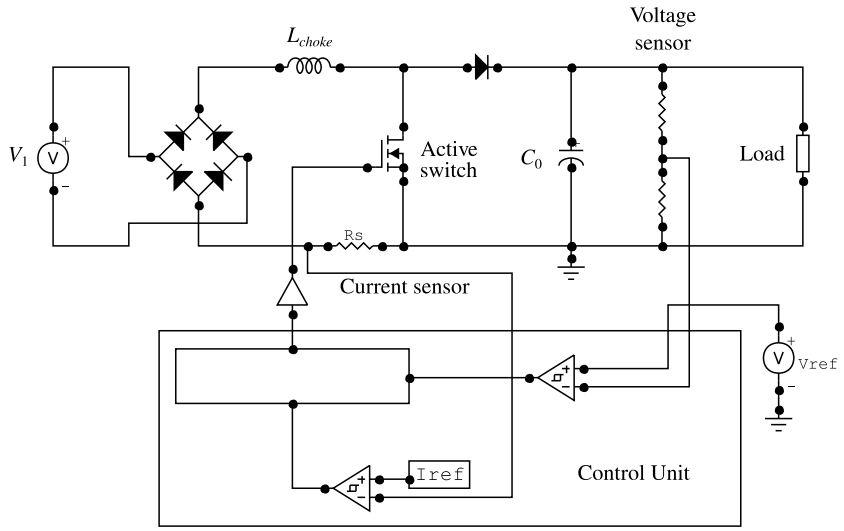
Figure 11

Boost converter current shaping circuit.



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Design of the control system for a thermal waste plant

Diseño del sistema de control de una planta de residuos térmicos

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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

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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,

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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.

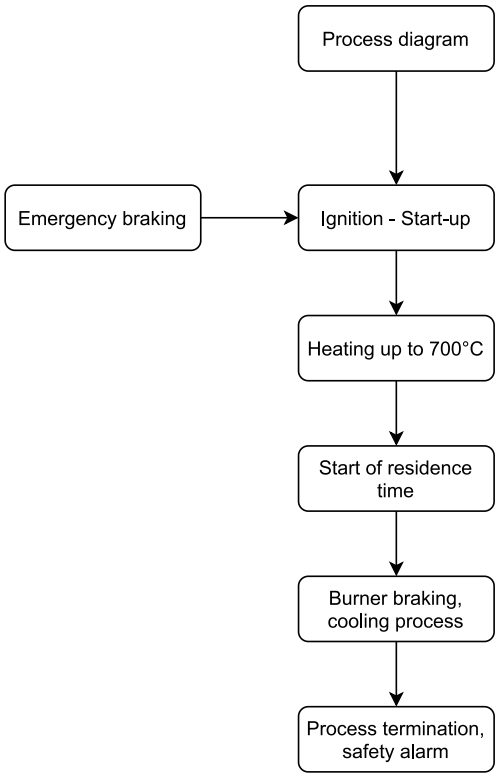
Design requirements

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.

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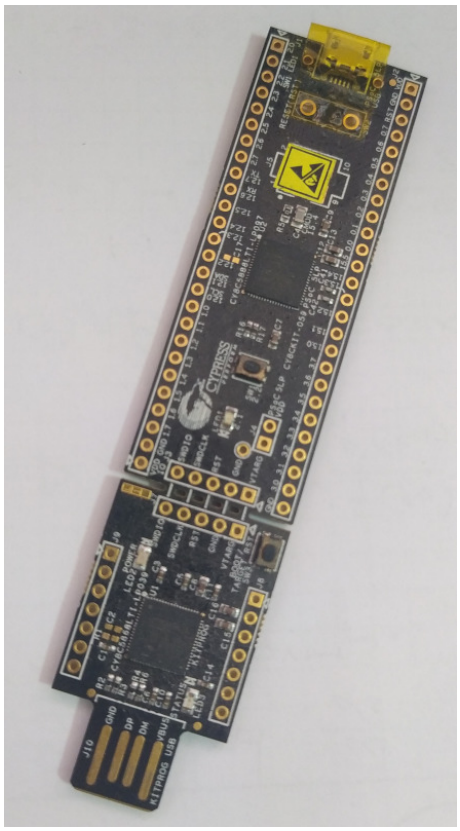
Figure 2

PSoC CY8CKIT-059.



Methods

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

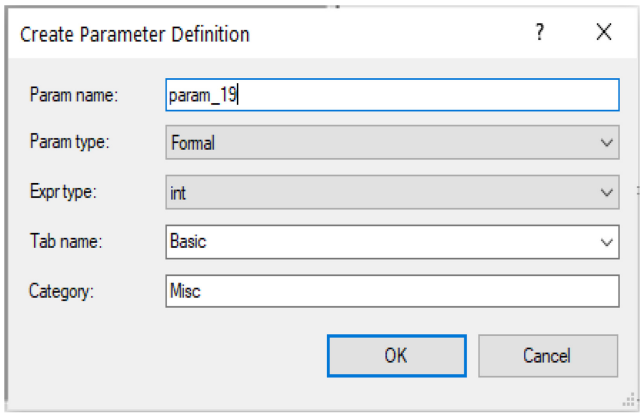
Control system

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

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Figure 4

Hardware parameter selection.

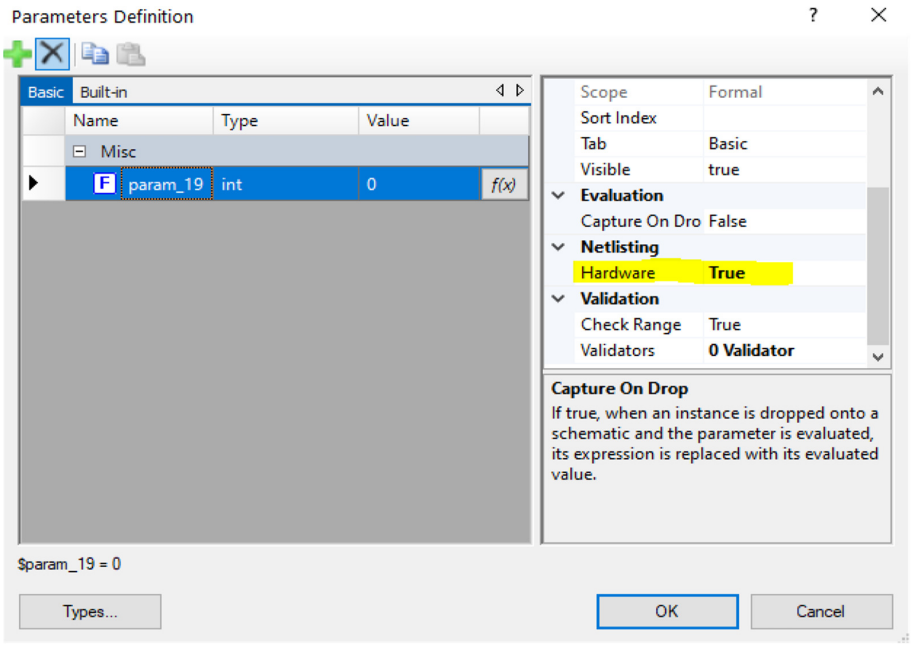
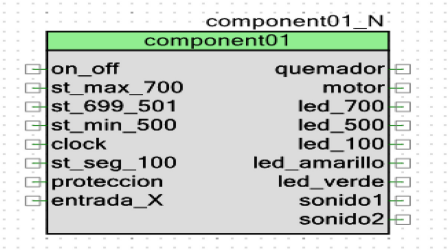


Figure 5

Component creation.



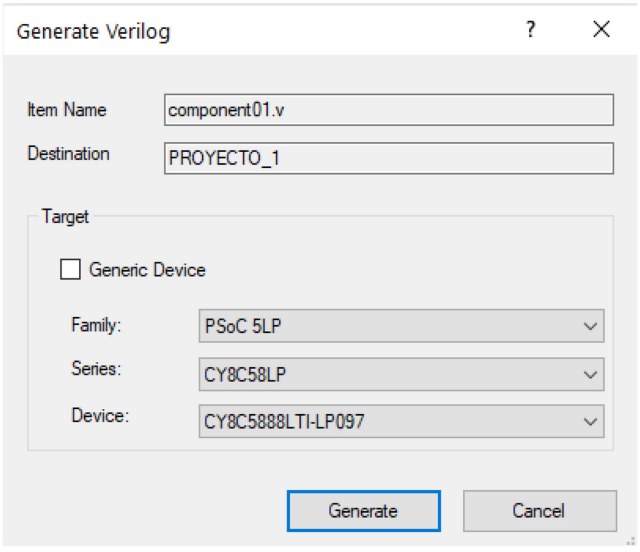
CLOCK signal is simulated for ease of use by a simple switch (Fig. 13).

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

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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

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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

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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).

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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).

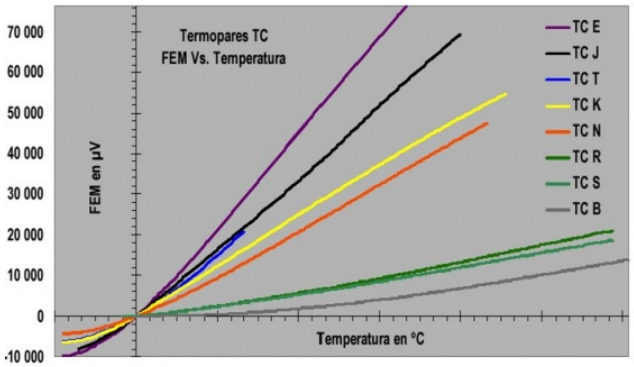

Figure 21

ADC component.

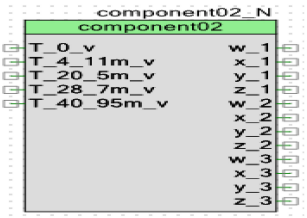

Figure 22

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.

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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.

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Figure 28

Creation of the component.

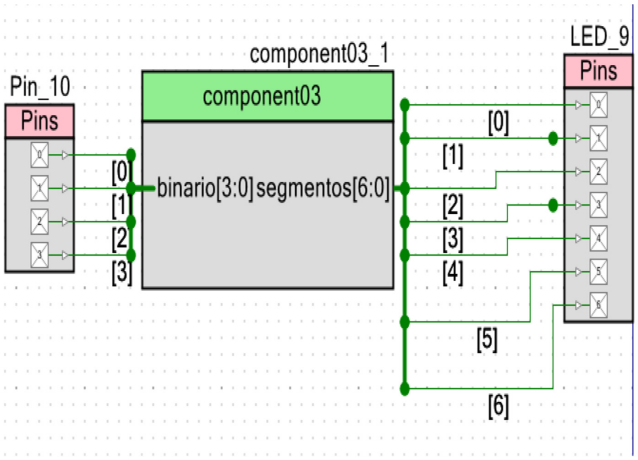

Figure 29

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

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Figure 31

Hardware assembly.

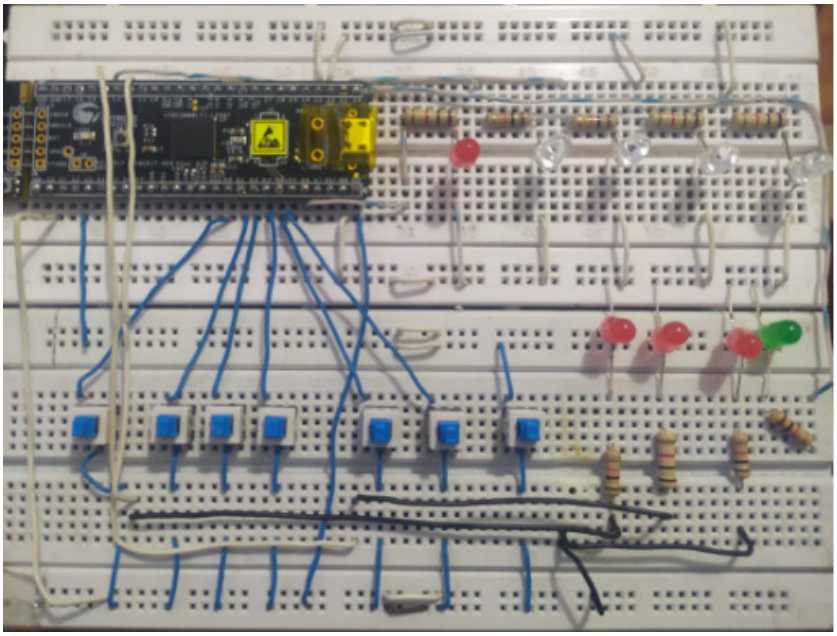

Figure 32

Pin layout in PSoC Creator.

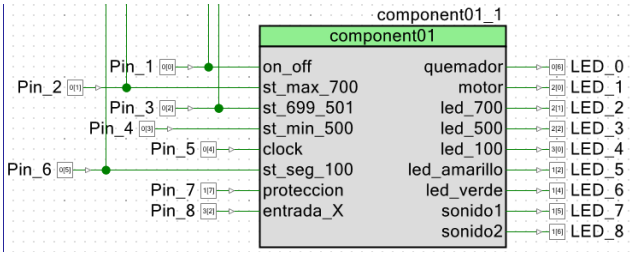

Figure 33

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.

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Figure 34

Definition of TestBench outputs.

```
module component01 (
  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.

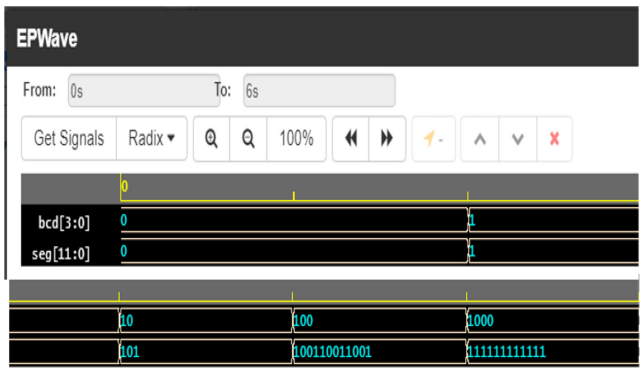


Figure 36

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
```

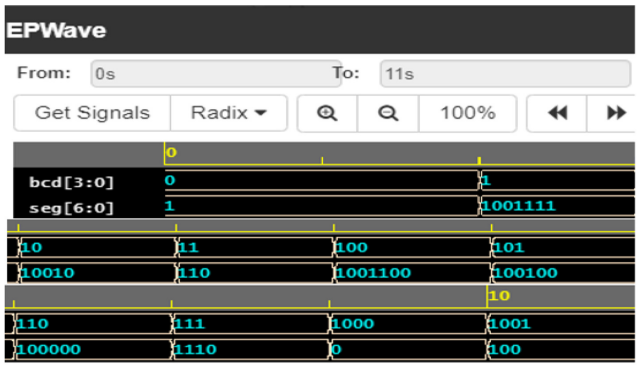
Figure 37

Definition of TestBench outputs.

```
module component01 (
    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.



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System for access control to a shopping mall

Sistema para el control de acceso a un centro comercial

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Sequential logic systems over the years have allowed an improvement in control and access systems. This article looks for a way to use this type of logic to create an autonomous system in Verilog for the access of people to a shopping mall, which should allow the realization of counts, movement analysis, and temperature detections, which allow avoiding the direct relationship with the security employees, making this way a protection measure for situations like the one that is currently being experienced with the global pandemic. This system, due to its configuration and accessibility, must be easy to understand, therefore the operation of this project is visualized with a traffic light configuration where green represents a positive action of entry, represents an alert or emergency. The system will give a stop signal, either for high temperatures or for people over or equal to the limits.

Keywords: Access control, control system, sequential logic, traffic light

Los sistemas de lógica secuencial a lo largo de los años han permitido un mejoramiento en los sistemas de control y de acceso. Este artículo busca la manera de usar este tipo de lógica para crear un sistema autónomo en Verilog de acceso de personas a un centro comercial, el cual debe permitir la realización de conteos, análisis de movimiento y detecciones de temperatura, que permitan evitar la relación directa con los empleados de seguridad haciendo de esta forma una medida de protección para situaciones como la que se está viviendo actualmente con la pandemia mundial. Este sistema, debido a su configuración y accesibilidad, debe ser de fácil comprensión, por esto el funcionamiento de este proyecto se visualiza con una configuración de semáforo en donde el verde representa una acción positiva de ingreso, mientras que el rojo representa una alerta o emergencia. El sistema dará una señal de alto, ya sea por altas temperaturas o por aforo de personas que sobrepase o iguale los limites.

Palabras clave: Control de acceso, lógica secuencial, semáforo, sistema de control

Article typology: Research

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Introduction

Over the years, technology and its implementation in security systems and access controls for shopping malls have improved significantly, due to the need to control the flow of people entering and leaving the mall, such controls have different purposes such as identification of workers, recognition of unauthorized personnel, early detection of threats among other problems or situations that may occur in places with high crowds of people (Cardona & Botero, 2017).

Currently, the access control systems of people have been forced to improve, but in general, are limited by motion sensors that only open and close their doors, this system is functional, but in terms of management and identification is obsolete, as it does not allow to have control of people entering the mall (Martínez et al., 2012). Due to the situation that the world is going through nowadays, it has become necessary to improve this type of system, since they must have control of the flow, quantity, and temperature of the users (Guerrero et al., 2017).

At this time the COVID-19 pandemic has changed the operation of the entrance to shopping centers, since the agglomeration of people in such places daily is quite frequent, one of the solutions that have been implemented are the manual temperature measurements, and controlled entry by security personnel, this process besides being inefficient, is unsafe for staff, as it exposes them to greater contact and exposure to the virus (Fernandez, 2019).

In this article we want to provide a solution to these problems through a system that allows us to quantify and control the entry of people, enabling entry and exit doors through motion and temperature sensors, these sensors allow us to know the number of people who are inside the mall, ensuring a maximum quota of people and the time that these individuals will last in the facilities, Taking into consideration that users can only enter to make purchases and specific transactions, this time will be better controlled with the system, in addition, the temperature sensor will allow making a selection of people who can enter, since high-temperature levels are one of the main symptoms generated by the COVID-19 virus (López et al., 2019).

The implementation of the system will be developed using the Verilog language, to codify the whole system and its behavior, since it allows complete control of the software and hardware, making the design of the circuits and logical combinations more optimal and efficient (Martínez & Castiblanco, 2011; Pardo, 2015).

The behavior of the system is similar to that of a traffic light since it is based on the same principle: when the number of people inside the shopping center is less than or equal to 100, the green signal will light up; if the temperature of any of the individuals entering is higher than allowed, an emergency signal will appear, represented by the color red, and so on with the different representations that will be used for the different situations (Galvis et al., 2011).

Problem Formulation

The world is currently undergoing abrupt changes due to the COVID-19 pandemic since existing medical advances are limited to controlling a problem of this nature, therefore, efforts to create a preventive vaccine against this virus have multiplied, despite this, the development of such vaccine has been advancing slowly, so so far the only option we have is to be prevented and protect ourselves by changing the way we live, think and relate to each other (Cooper & Stowe, 2018).

The COVID-19 virus is transmitted quickly and easily between people, it is only enough to come into contact with air that has attached particles of the virus to become infected (Diaz & Mendez, 2019), for the moment social distancing is one of the most effective ways to avoid contagion since it allows separating people who may be carriers of the virus and who do not know it from healthy people (Penaranda & José, 2016), for this reason, many places with possible agglomerations have had to close their doors causing millionaire losses, one of these places are shopping malls. Shopping malls apart from being a meeting place where you can interact, socialize and meet the needs of leisure and entertainment, are now places that offer various services that can be considered of vital importance to people, such as banks, pharmacies, supermarkets among others, for this reason, it was necessary to find a solution so that people can access the malls without exposing themselves to a possible contagion.

Shopping malls have opted for not very efficient methods that put the lives of their employees at risk, in addition to this there is no relevant control of the number of people entering and leaving the establishment (Martínez & Castiblanco, 2010). In the present article an autonomous system is designed that allows to have access controls for a shopping center, this consists of three enabled entrance doors and one exit door, in the entrances there are three sensors that detect when the person enters, in addition these three sensors detect the body temperature, when the person enters the shopping center the sensors deliver a logical 1, In this way, if there are more than 100 people inside the mall, a red light will turn on and no more people will be allowed to enter, otherwise the light will be green and one person will be allowed to enter every 30 seconds, the temperature sensors in each door will give a logical 0 if the person's temperature is lower than 37.6 degrees, otherwise the sensor will deliver a logical 1 that will activate an emergency signal and a red light, at the exit a sensor delivers a logical 1 when it detects the exit of a person otherwise a logical 0, with this autonomous system guarantees a certain number of people inside the mall thus allowing social distancing, it also ensures that people entering the mall do not have one of the main symptoms of

COVID-19 (Pencue et al., 2015). Although the principle of operation is based on simple sensors, its design is efficient, inexpensive and easy to implement.

The rest of this paper is structured as follows. Section 2 presents the general formulation of the problem addressed. Section 3 details the design methodology, including the modules and the Verilog code used. Section 4 presents the behavior utilizing simulation, and finally, in the last section, we present the conclusions.

Research Method

The design to be carried out in this project is intended to be an autonomous system in Verilog language for the control of access to people to a shopping center, for this purpose the procedure and methodology presented below should be implemented (Escobar et al., 2008).

1. The inputs and outputs of the shopping center are determined to know which components will be used in the Verilog coding.

2. Sensors S.IG1, S.IG2, S.IG3, and the infrared thermal sensor will be located at all entrance doors, and the S.OG1 sensor at the exit door. In addition, security and surveillance personnel must be available to keep the flow of people controlled in one direction only.

3. The code thought to realize this system starts with a first filter consisting of an infrared thermal sensor, which when detecting a temperature lower than 37.6 degrees centigrade the sensor will deliver a logic code 10 which will turn on a green light (OKG1, OKG2, or OKG3) to allow entry, otherwise the sensor will deliver a logic code 01 which will activate an emergency signal at the corresponding door (red light OEG1, OEG2 or OEG3).

4. After the first filter, at the inputs (IG1, IG2, and IG3) there will be sensors S.IG1, S.IG2, and S.IG3 that will deliver a logical code 1 when the person enters, these signals will reach a module that we will call counter, which will turn on a red light when the number of logical 1's representing the entry of each person is 100, otherwise, it will turn on a green light 4 seconds every 30 seconds, at the exit door OG1 there is the sensor S.OG1 delivers a logic one when a person passes through it, indicating in any of the inputs IG1, IG2, and IG3 that another person can enter.

Access and counting module

A module is created for each door that allows access to people who do not have a temperature higher than 37 degrees Celsius, it also allows counting the number of people entering through each door, as the modules for the three entrance doors work in the same way only the operation of the first module will be described (Figs. 1, 2, and 3).

The access and counting module has two inputs called SensorMov and SensoTemp, when the SensorMov detects a person it sends a logical 1 to the system, and the SensorTemp measures the body temperature of the person who was detected by the SensorMov, if it is higher than 37 degrees Celsius an emergency signal is activated which we call SalidaR, which will show a logical 01 indicating the alert and thus denying the entrance to the Mall, otherwise the OutputV will be activated and will show a logical 10 indicating that the person can enter when this condition is met, the person will be counted as entering the Mall.

Final adder module

A module is created in which information is received on how many people have entered the mall through the three entrance doors and how many people have left through a single exit door, in order to constantly count the number of people inside the mall, so that in no way the number of people inside the mall exceeds 100 people.

The final summing module has four inputs Entr1, Entra2, Entr3 and SensorS, the first three inputs are responsible for entering the module the number of people who have entered the mall for each of the three doors, in this way the module will add the total number of people who have entered the mall, also subtract one person to the total of the previous sum, when the movement sensor at the exit of the mall detects that a person has left, if the total number of people inside the mall is between zero and 100, the SV exit will be activated, which will indicate at the doors one, two and three, that access to the mall is still allowed, otherwise the SR exit will be activated, which will indicate at the three entrance doors that the mall will no longer allow access to the mall (Figs. 4, 5, 6, and 7).

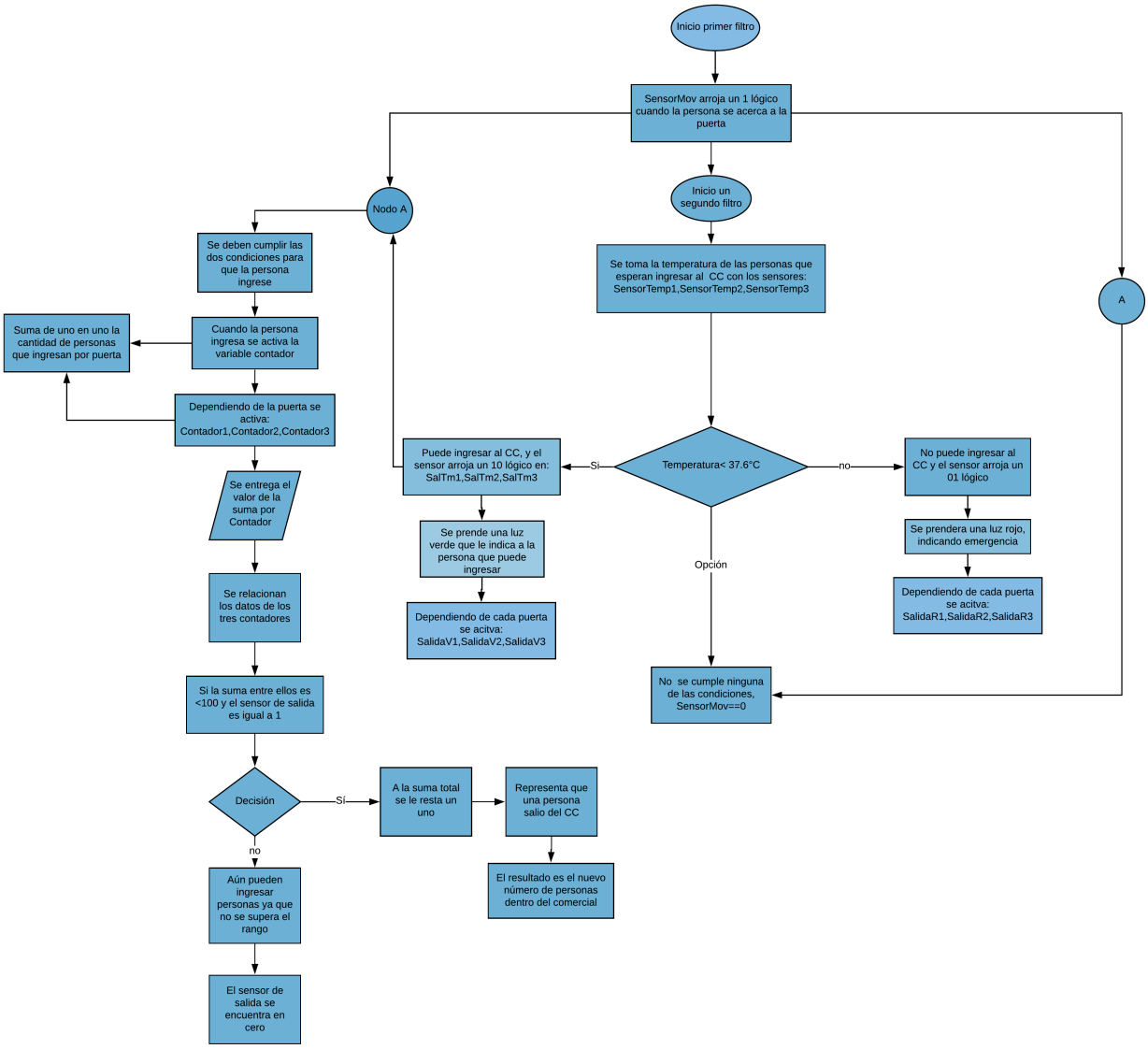
Results and Discussion

The results obtained in the simulations are presented in Fig. 8 and Fig. 9. As part of the analysis of these simulations, the codes and their operation in the EDAplayground simulator were taken into consideration. The network used in the EDAplayground simulator is a VLSI net that transforms Boolean circuits into equations of the form $(c_j = g_i(e_{ij}))$ where (c_j) represents a Boolean circuit.

The first simulation (Fig. 8) represents the result of the coding performed for door number one, which is intended to perform three actions that are related but work independently. First: detect the movement of a person outside the door, second: measure the temperature of the detected person, and third: if the conditions are met, the person will be counted as entering the mall. With these parameters and the results visualized in EDAplayground, it can be said that the designed code works correctly.

Figure 1

Flowchart.



In the simulation, to check the operation of the code, four possible cases that may occur if the system is in operation were placed, for the first case the temperature of the person was less than 37 degrees Celsius, therefore, the counter variable indicated that a person met the requirements and therefore had entered the mall, In the next two cases, as the measured temperature was also lower, only the increase in the counter and the measured value were shown; the other specifications remained constant until the change in the last case. This case showed a different condition, since the temperature measured by the sensor was 38 degrees Celsius, so it changed the other variables, turning on the alarm and taking a logical 01, with this last case the operation of the counter was checked since the conditions were not met, leaving the counter variable as it was when the conditions were true until a new case is presented.

For the second simulation (Fig. 9), the purpose was to test the operation of the last module, which was in charge of determining the total number of people inside the mall and the final total when a person exited the mall, taking into consideration that if the initial number of people was equal to 100, then no person could enter until an exit was detected, taking into account this, two possible cases were considered.

Figure 2

Block diagram.

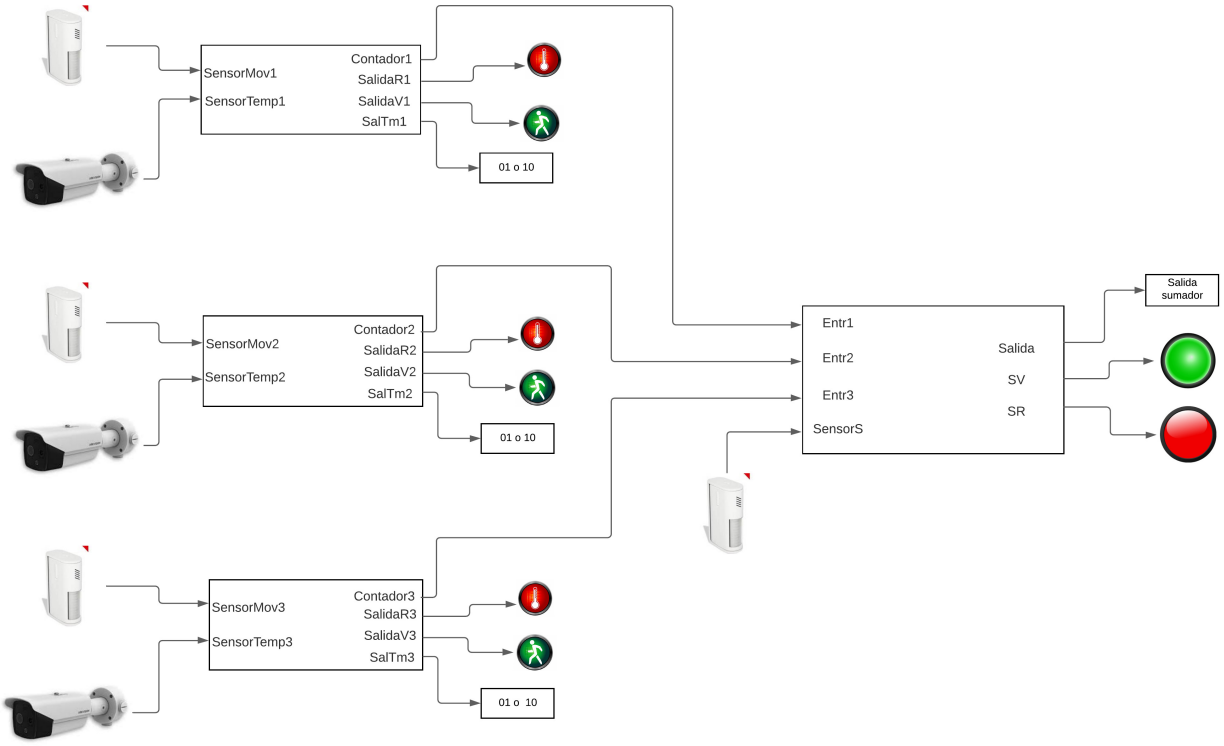


Figure 3

System modules.

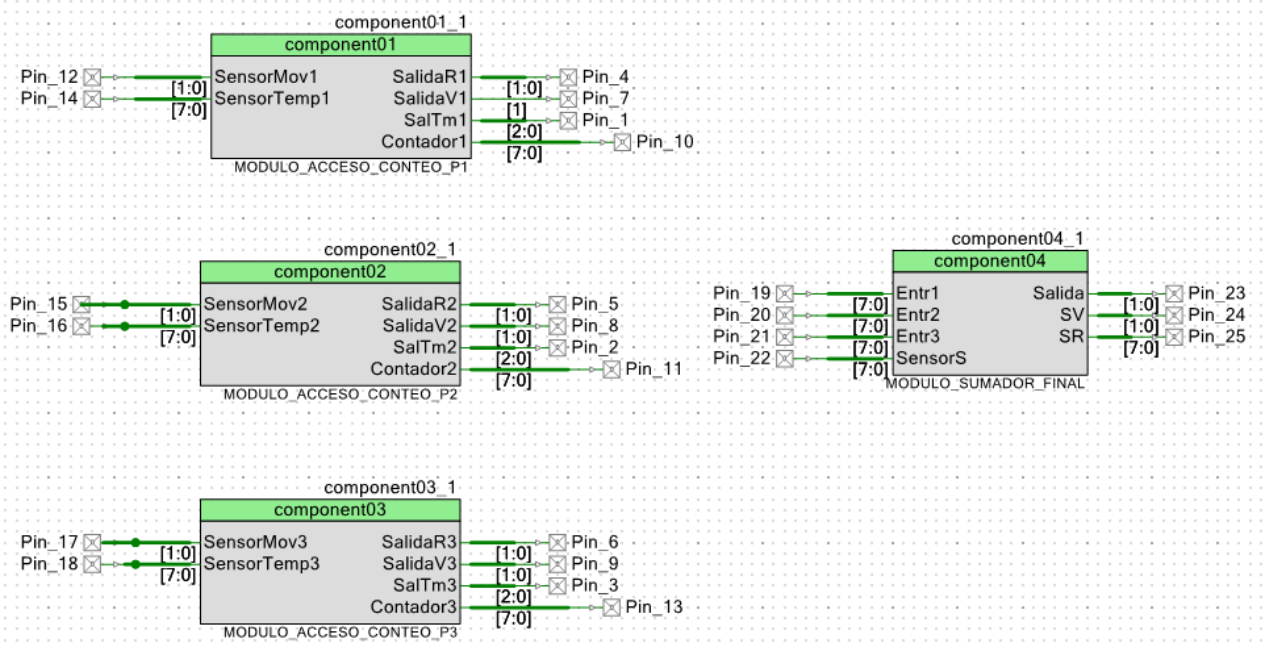


Figure 4

Code for access and counting module.

```
module component01 (
    output reg [7:0] Contador1,//Salida con el total de ingresos por persona en la puerta 1.
    output reg [1:0] SalidaR1,//Salida para luz roja de advertencia.
    output reg [2:0] SalidaV1,//Salida para luz verde indica a la persona que puede ingresar.
    output reg [2:0] SalTm1,//Salida a Dsiplay, si la persona tiene fiebre o no.
    input wire [1:0] SensorMov1, // Sensor de Movimiento.
    input wire [7:0] SensorTemp1 // Sensor de temperatura.
);
    parameter param_19 = 0;

//Indicamos que la entrada Contador inicia en estado  0.
initial Contador1=1'b0;

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

//        Your code goes here

always @ (SensorMov1 or SensorTemp1)
    begin
//Condiciones para que la persona pueda o no ingresar al CC.
//Temperatura mayor a 37°C no puede ingresar al CC.
    if(SensorMov1==1)
      if(SensorTemp1>=8'b00100101)
        begin
        SalTm1=2'b01;
        SalidaR1=1;
        SalidaV1=0;
        end
//Temperatura menor a 37°C la persona puede ingresar
      else
        begin
        SalTm1=2'b10;
        SalidaR1=0;
        SalidaV1=1;
        Contador1<=Contador1+1;
        end
    else
      begin
      SalTm1=1'b0;
      SalidaR1=0;
      SalidaV1=0;
      end
    end

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

Conclusion

As a consequence of what has been exposed in the present article, it has been possible to determine that the sequential systems help to give solutions to the diverse problems that can be presented in difficult times. For this reason, it is of great utility to expose the forms of management, development, and control that can have a common digital system, which can be implemented in situations in which quantity or veracity controls are needed. In an introduction that can be seen as one of the central themes of our article, we have exposed the elements in which management, development, and control have a common system that can be implemented in situations where quantity or veracity controls are needed.

Similarly, we believe it is important to note that the functions represented by the traffic light configuration, and by the movement and temperature modules can be very useful, not only for access control but also for systems

Figure 5

Code for total adder module.

```
module component04 (
    output reg [7:0] Salida,//Indica el total de las entradas 1, 2 y 3.
    output reg [1:0] SR,    //Indica que hay menos de 100 personas en el CC.
    output reg [1:0] SV,    //Indica que hay 100 personas en el CC.
    input wire[7:0] Entr1,  //Indica el total de ingresos por la puerta 1.
    input wire[7:0] Entr2,  //Indica el total de ingresos por la puerta 2.
    input wire[7:0] Entr3,  //Indica el total de ingresos por la puerta 1.
    input wire[1:0] SensorS //Indica la salida de una persona por la puerta de salida.
);
    parameter param_19 = 0;

initial Salida=1'b0;

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

//        Your code goes here
always @ (Entr1 or Entr2 or Entr3 or SensorS)
//Si en el CC hay menos de 100 personas y el sensor de salida indica
//una salida, sumar el total de puerta 1, 2 y 3 y restar una salida.
    if(8'b00000000<Salida<8'b01100100 && SensorS==1'b1)
        begin
        Salida=Entr1+Entr2+Entr3;
        Salida=Salida-SensorS;
        SV=1;
        SR=0;
        end
    else
        begin
        SR=1;
        SV=0;
        end

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

that need to control the flow of people depending on special parameters, therefore, with this coding we can relate the independent variables with dependent factors of other behaviors, at the end of it the results can be as for the present case mostly positive. The purpose of traffic signals is to manage the flow of people.

In general, the applications for sequential and combinational systems can have a diversity of functions, therefore, the advances made with these systems must be presented and worked correctly, since they can be used as the basis for more complex programs and developments. It is because of its diversity and complexity that the most advanced applications of sequential systems are now being applied to, among other things, air traffic control systems, communication networks, and military command-and-control.

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Figure 6

Simulation code access and counting module.

```
//testbench.sv
module Prueba;
  reg [1:0] SensorMov1;
  reg [7:0] SensorTemp1;
  wire [7:0] Contador1;
  wire [1:0] SalidaR1;
  wire [2:0] SalidaV1;
  wire [2:0] SalTm1;

  component01
Modulo_Puerta_1(SalidaR1,SalidaV1,SalTm1,Contador1,SensorMov1,SensorTemp1);

    initial begin
      $dumpfile("dump.vcd");
      $dumpvars(1,Prueba);

      SensorMov1=1'b0;
      SensorTemp1=8'b00000000;

     SensorMov1=1'b1;
     SensorTemp1=8'b00100100;
     #1

     SensorMov1=1'b1;
     SensorTemp1=8'b00100010;
     #1

     SensorMov1=1'b1;
     SensorTemp1=8'b00100001;
     #1

     SensorMov1=1'b1;
     SensorTemp1=8'b00100110;
     #1
      $finish;
    end

endmodule
```

```
//Desing.sv
module component01 (
  output reg [1:0] SalidaR1,
  output reg [2:0] SalidaV1,
  output reg [2:0] SalTm1,
  output reg [7:0] Contador1,
  input wire [1:0] SensorMov1,
  input wire [7:0] SensorTemp1
);
    parameter param_19 = 0;

initial Contador1=1'b0;
//        Your code goes here
  always @ (SensorMov1 or SensorTemp1)
    begin
    if(SensorMov1==1)
      if(SensorTemp1>=8'b00100101)
        begin
        SalTm1=2'b01;
        SalidaR1=1;
        SalidaV1=0;
        end
      else
        begin
        SalTm1=2'b10;
        SalidaR1=0;
        SalidaV1=1;
        Contador1<=Contador1+1;
        end
    else
      begin
      SalTm1=1'b0;
      SalidaR1=0;
      SalidaV1=0;
      end
    end
//`#end` -- edit above this line, do not edit this line
endmodule
```

Figure 7

Simulation code final adder module.

```
//testbench.sv
module Prueba;

  wire [7:0] Salida;
  wire [1:0] SV;
  wire [1:0] SR;
  reg [7:0] Entr1;
  reg [7:0] Entr2;
  reg [7:0] Entr3;
  reg [1:0] SensorS;

  component04 Modulo_Contador(Salida,SV,SR,Entr1,Entr2,Entr3,SensorS);

    initial begin
      $dumpfile("dump.vcd");
      $dumpvars(1,Prueba);

      Entr1=8'b00000000;
      Entr2=8'b00000000;
      Entr3=8'b00000000;
      SensorS=1'b0;

      Entr1=8'b00010100;
      Entr2=8'b00001010;
      Entr3=8'b00001111;
      SensorS=1'b1;
      #1

      Entr1=8'b01000001;
      Entr2=8'b00001010;
      Entr3=8'b00001111;
      SensorS=1'b0;
      #1

      $finish;

    end
endmodule
```

```
//Desing.sv
module component04 (
  output reg [7:0] Salida,
  output reg [1:0] SV,
  output reg [1:0] SR,
  input wire [7:0] Entr1,
  input wire [7:0] Entr2,
  input wire [7:0] Entr3,
  input wire [1:0] SensorS
);
    parameter param_19 = 0;

initial Salida=1'b0;

//        Your code goes here

  always @ (Entr1 or Entr2 or Entr3 or SensorS)
    if(8'b00000000<Salida<8'b01100100 && SensorS==1'b1)
    begin
    Salida=Entr1+Entr2+Entr3;
    Salida=Salida-SensorS;
    SV=1;
    SR=0;
    end
  else
    begin
      SR=1;
      SV=0;
    end

endmodule
```

Figure 8

Simulation Module 1 (Puerta1).

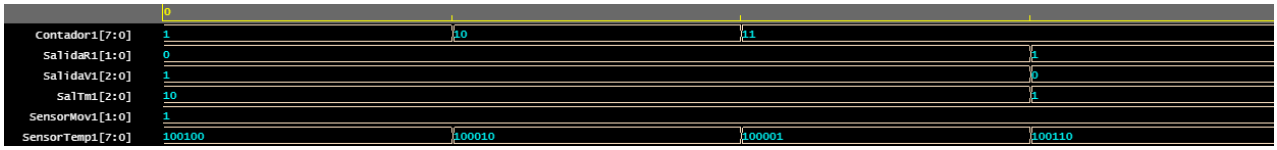
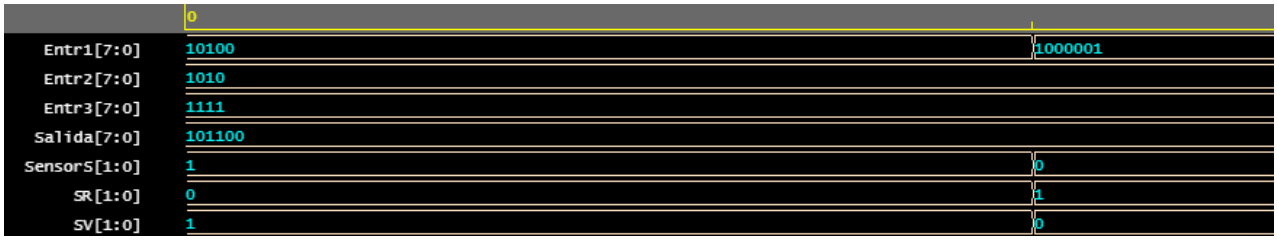


Figure 9

Simulation Module 4 (Contador).



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Password-based vehicle access control system for parking lots designed and simulated in Verilog

Sistema de control de acceso de vehículos a estacionamientos con contraseña diseñado y simulado en Verilog

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This paper presents a low-cost embedded system for vehicle entry and exit control in conventional parking lots. Given the pandemic situation, the system seeks to ensure security and service optimization and reduce contact with security staff. The design of a sensor-activated control system that prompts the user for a password to enter or exit the parking lot is presented. In addition, the system incorporates a security alarm that is activated if the user enters the wrong password three times in a row. The simulation was performed by modules that refer to the data flow. The design of the digital components was done in Verilog. The results are successful; the system has a low implementation cost and does not require external components.

Keywords: Control system, digital system, parking lot, security

En este artículo se presenta un sistema embebido de control de ingreso y salida de vehículos en parqueaderos convencionales de bajo costo. El sistema busca garantizar seguridad y optimización del servicio, y además reducir el contacto con el personal de seguridad dada la situación de pandemia. Se presenta el diseño de un sistema de control activado por sensores que solicita al usuario una contraseña para poder entrar o salir del parqueadero. El sistema incorpora una alarma de seguridad que se activa en caso de que este ingrese la contraseña incorrecta tres veces seguidas. La simulación se realizó por módulos que hacen referencia al flujo de datos. El diseño de los componentes digitales se realizó en Verilog. Los resultados obtenidos son satisfactorios, el sistema tiene un bajo coste de implementación y no requiere de componentes externos.

Palabras clave: Parqueadero, seguridad, sistema digital, sistema de control

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Introduction

Currently, many parking lot entry and exit control systems are carried out manually by security personnel. This results in a late and suboptimal parking lot management process, generating traffic at the entrances and exits. In addition, there is no control over the number of vehicles entering and exiting, which creates uncertainty regarding available space (Puranic et al., 2016; Widodo et al., 2020). The cost of an automated parking lot security system can be offset by productivity improvements and customer satisfaction resulting from a higher utilization rate for the parking lot.

Since automated systems have been implemented to solve the aforementioned problems, some of which are described below, there has been increased productivity and customer satisfaction. The parking lot security system is improved due to reduced road closures, automated toll collection in many locations, and the ability to control the number of cars allowed in and out of parking lots.

Biometric control systems are intended to restrict vehicle access according to the physical characteristics of the vehicle user, such as eye iris, eye retina, face geometry, hand vein pattern, fingerprint, hand geometry, voice, ear shape, etc. (Boriev et al., 2016; Buenano et al., 2009; Lourdes, 2017). Each of these characteristics is mapped to a unique code, which prevents access when the vehicle driver does not possess the corresponding code. Biometric systems have been deployed in numerous industries, including the U.S.

ALPR systems control vehicle access to restricted areas by applying artificial vision to recognize, fragment, and segment the characters of vehicle license plates based on images or videos taken by cameras (Martínez et al., 2018; Martınez et al., 2018; Montiel et al., 2018). Thus, only vehicles with specific license plates can access a particular area (Mohandes et al., 2016; Puranic et al., 2016). Local law enforcement agencies have been using ALPR to reduce crime and improve highway safety.

RFID systems are based on recognizing tags using radio frequency at a certain distance and frequency. The tags are devices consisting of a microchip and an antenna. These are incorporated into vehicles so that their recognition allows access to a specific area (Pala & Inanc, 2007; Zhou & Zhihua, 2016). Tags are affixed to the sides of license plates, fixed to a special paper that identifies the owner.

Other control systems include automatic vehicle barriers and electromechanical arms. However, the abovementioned strategies imply a high development complexity and an increased investment cost. That is why we are interested in designing a simple and efficient control system that does not generate high prices at the time of implementation in a parking lot.

This project aims to design a system for vehicle access to parking lots through the entry of a single password per user. The project is intended for a parking lot with two entrances and one exit. The system will be designed with the Verilog hardware description language; it will consist of the detection of vehicles from sensors and the activation of the access levers according to the password entered by the user. In addition, a security alarm will be provided in case of multiple errors when entering the password.

The system will allow the control of the vehicles in the parking lot for a better management of availability, and will perform the procedure of control of entry and exit of vehicles in a more optimal way. In addition, it will offer a secure and automated way to do so since it is implemented on a small embedded system (Galvis & Madrid, 2016).

Problem Statement

Currently, some parking lots have antiquated systems for controlling the entry and exit of vehicles, such as the manual systems used by security personnel, which have security and service optimization problems (Boriev et al., 2016; Buenano et al., 2009).

Some of the problems highlighted in the conventional control systems are theft of vehicles or vehicle accessories, superficial vehicle damage, late management of the parking lot, traffic in the entrance areas, inconveniences with identity verification, etc. Added to this, with the current situation of COVID-19, continuous contact with security personnel becomes a problem.

In the market, some solutions propose the automation of control systems, but many have a high implementation cost that does not justify their installation in parking lots. That is why the need arises for a control system that is not very complex, economical, and easy to implement for conventional parking.

Most systems on the market require very complex integrated systems since they are based on particular characteristics of users, such as biometric systems or license plate recognition. This means that the technology is very sophisticated and requires external components such as high-level equipment, which is why its implementation is not justifiable in any parking lot.

Is it possible to design and simulate a simple, safe, and economically viable vehicle entry and exit control system for conventional parking lots?

The solution to the problem is to design a vehicle entry and exit control system based on a password, which is requested when a sensor detects the presence of a vehicle at the entrance or exit of the parking lot; the validation of the password will result in the opening of the entry lever; on the other hand, if it is entered three times incorrectly, a security alert will be triggered. The system described above will be designed with the Verilog hardware description language.

Research Method

The modules shown in the flowchart in Fig. 1 are programmed using the Verilog hardware description language. In the following, we will briefly discuss how to develop each of the modules.

Password entry in BCD

The first module consists of a numeric keypad where the user can enter the four characters of the password. There will also be an OK button to transmit the password information to the entire login control system.

A module with a single nine-bit input and a single 4-bit binary output will be used, its programming will be based on the always statement and the case function will be used to describe each of the input digit possibilities.

Binary password entry

This module is in charge of making sure that the four characters of the password occupy an independent space each, so that the password can be entered completely. For this, the module will be sensitive to each keystroke made by the user, with each keystroke the position of the character will advance to the next, until completing the four positions of the password.

This module will be programmed with the always statement, it will have as input the binary output of the first module and as output the four positions of the password. The module will be based on a demultiplexer, which will have four output channels that represent the characters of the password. This with the difference that the switches that control the channel that is shown at the output will vary their position according to the keystrokes made by the user.

Graphical interface

The password entered by the user can be displayed through a graphical interface consisting of four seven-segment LEDs.

For this, a module will be used in which each character position of the password in binary will have a respective value in the 7 segments. The 7 segments will show the numerical value in decimal of each password position.

The simulation will be based on a 7-segment common anode display.

Password verification

This module receives the four password characters and compares them with the correct passwords, if the password is incorrect it sends the data to an error counter that goes up to number three, on the contrary, if it is correct it sends a logical one to the door status module,

The module uses the always statement and is based on a simple else if loop, which sends a single true and an error signal of up to three bits, which allows counting the number of errors. Once a success is detected in the password the error counter is reset.

Door and alarm condition

This module is in charge of defining the status of the door based on several variables such as the correct password, the error counter, the sensor and the manual operation input. The gate states are defined as a two-bit bus, each combination representing one state as shown in Table 1.

Table 1

Coding of door states

Entry Signal	Door Action
00	Maintain current status
01	Open the door
10	Close the door
11	Remove power for manual operation

On the other hand, the alarm is activated only with a logic one, and remains off when it receives a logic zero.

Considering this, the module will have as output the state of the two-bit gate and the one-bit alarm. The module will work with an else if block, which contains all the conventional combinations of the different inputs and the combinations that are not there will have a gate status of 00 and alarm off.

Fig. 2 shows the block diagram by which the connection of the modules and therefore the control system is represented.

Results and Discussion

All modules were simulated in the online software Playground, where different combinations of the layers of each module were injected.

Password entry in BCD

Fig. 3 shows the component created in the PSoC Creator software corresponding to module 1. Fig. 3 shows the inputs and outputs of the module. All the number options that could be typed by the user on the numeric keypad were simulated, the results are shown in Fig. 4.

Figure 1

Control system flowchart.

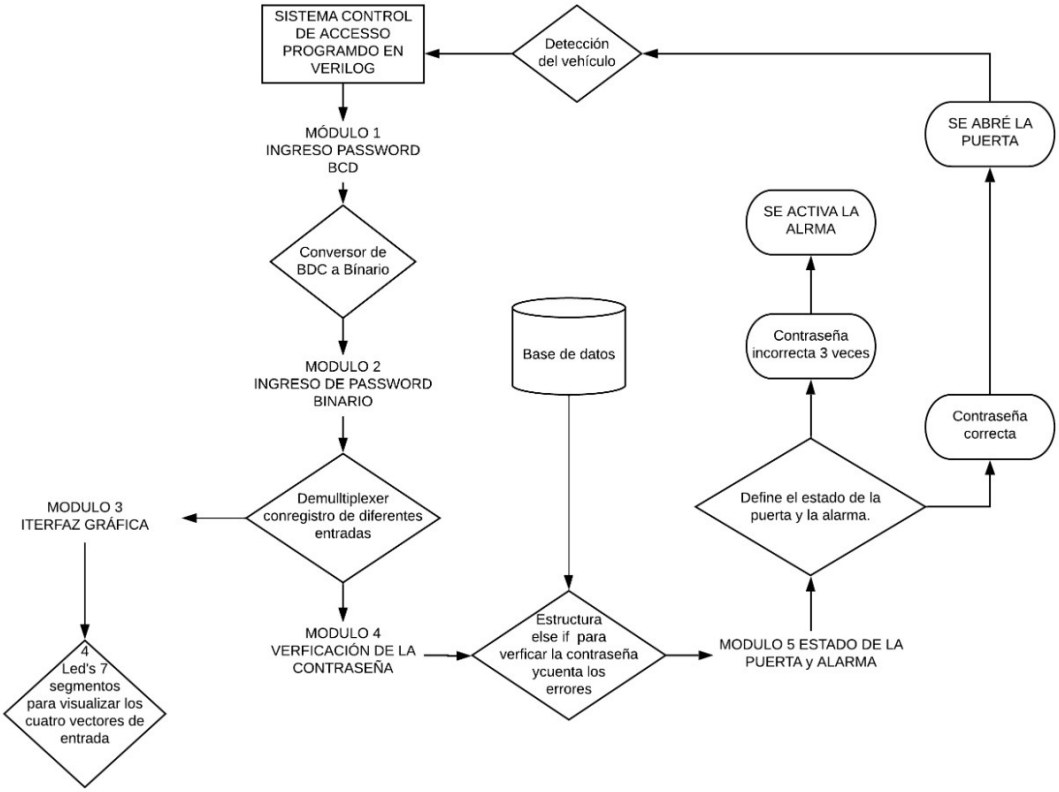


Figure 2

Block diagram of the control system.

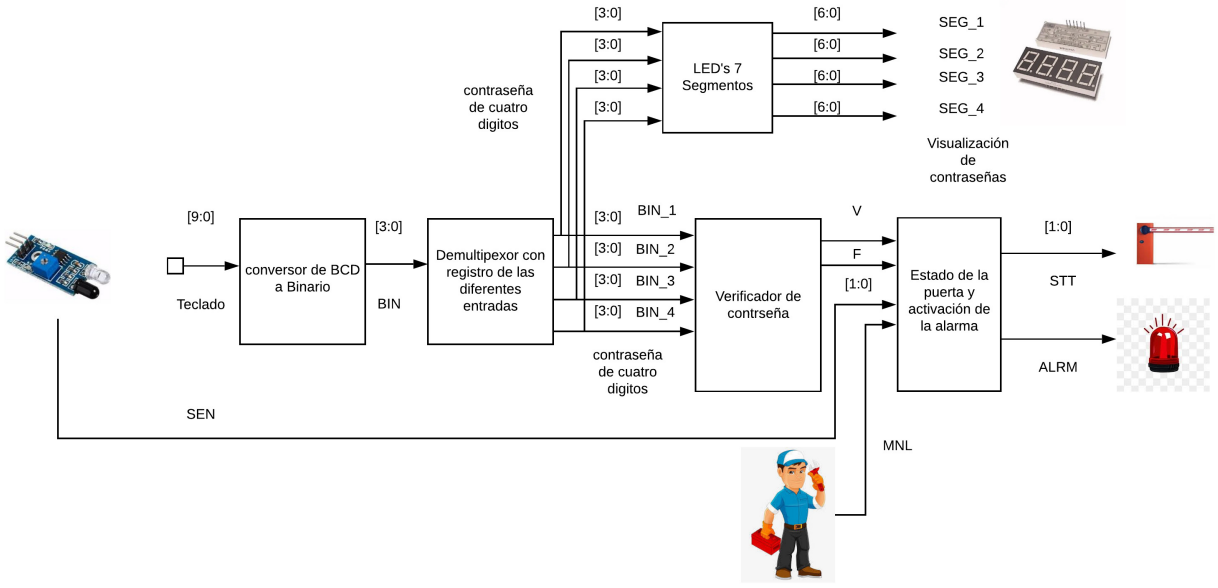
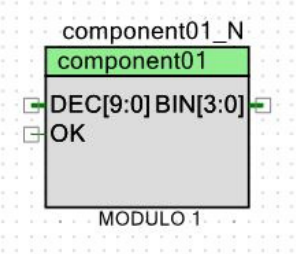


Figure 3

Component module 1.



As can be seen in Fig. 4, it shows the presses of a single button that has as representation a binary number in BCD.

Binary password entry

For module 2, the four keystrokes of the user were simulated and how each one of them occupied an output position of the user in binary. Fig. 5 shows the image of the component created in PSoC Creator corresponding to module 2.

Figure 5

Component module 2.

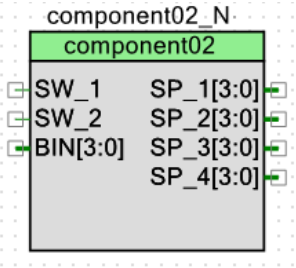


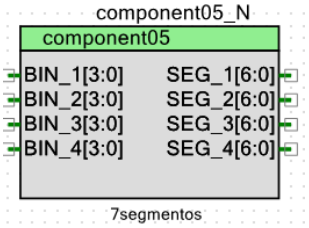
Fig. 6 shows how the user enters the password *1298* and how each of the characters is placed in an output position of the module. It can be affirmed then the correct operation of the same one.

Graphical interface

For the graphic interface we used a single module that will show the representation of the digits selected by the user in four seven-segment LEDs of common anode, one seven-segment LED for each character of the password. Fig. 7 shows the component created in Verilog for this module.

Figure 7

Component module 3.



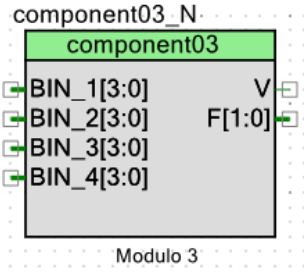
The simulation describes the behavior of a single seven-segment LED when pressed by the user and the others are ignored since the behavior is exactly the same for the other three. The simulation is shown in Fig. 8. All the digits that the 7-segment display represents are shown there.

Password verification

In this module, the counting of errors and the signal corresponding to the success of the password was simulated, for this purpose, data buses corresponding to correct and incorrect passwords were injected in order to verify the proper functioning of this important module. Fig. 9 shows the component created in Verilog corresponding to this module.

Figure 9

Component module 4.



In the simulation, three correct passwords were entered, resulting in three correct password 'V' signals in one. Subsequently a wrong password was entered and it was observed that the error signal 'F' changed state to 1 and the 'V' signal changed to low. Following this, three wrong passwords were entered and it could be seen how the errors were counted in the output 'F'. The simulation can be seen in Fig. 10.

Door and alarm condition

For the simulation of this module, all the door states were obtained according to the different inputs (V, F, Sensor, Manual intervention). The component created for this module is shown in Fig. 11.

Figure 4

Simulation of module 1.

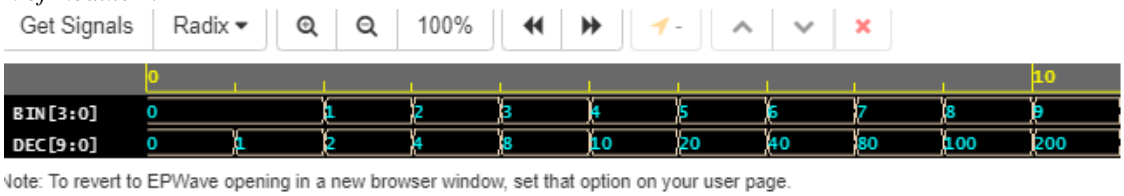


Figure 6

Simulation of module 2.

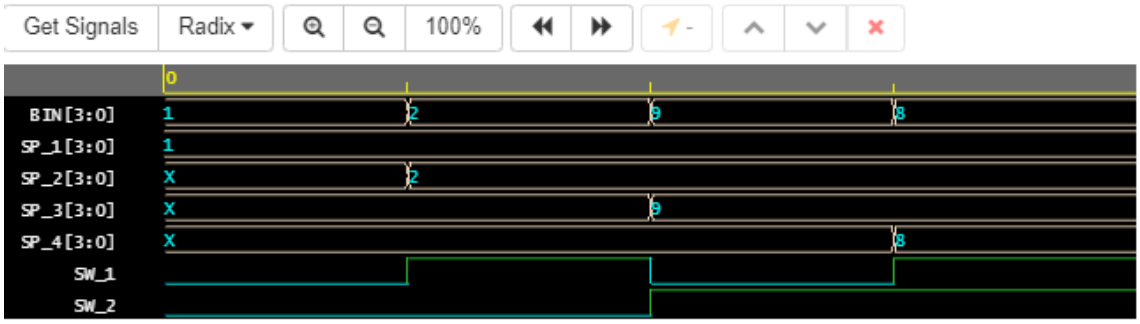


Figure 8

Simulation of module 3.

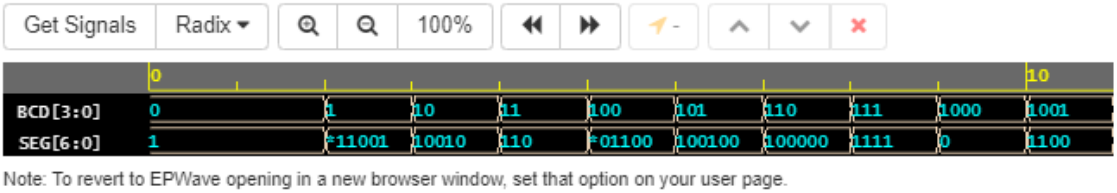


Figure 10

Simulation of module 4.

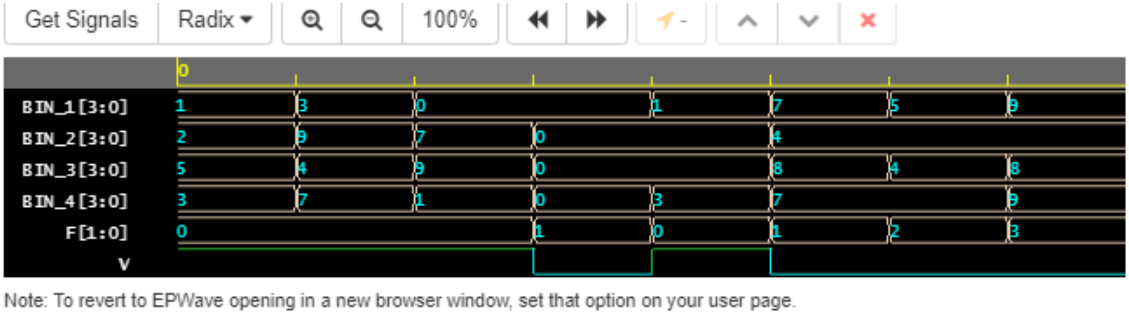
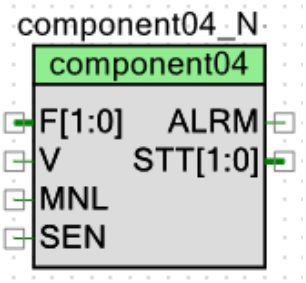


Figure 11

Component module 5.



The values given to the inputs in the simulation allowed us to check the positions of the 'STT' door according to the basic criteria, you can see a case in which three errors are received, therefore the door remains in its current state (closed) and the 'ALRM' alarm is activated, or how when the sensor is at zero the door is ordered to close since there is no vehicle present, which means that the vehicle has already entered. It can also be seen that when the password signal 'V' is high and the door opens and so on, until obtaining all the states of the door according to their inputs. The simulation can be seen in Fig. 12.

Conclusion

It can be observed that the control system works satisfactorily according to the parameters indicated in the methodology; this is according to the effectiveness of the simulation of each of the proposed modules. This suggests that the control system will behave adequately in a future implementation in an actual parking lot.

Within the analysis presented above concerning a vehicle access control system, the results indicate that the implementation of a security system using a password to replace systems such as bioelectrical detectors, ALPR systems, RFID, and automatic barriers is reliable since our system makes use of free software, hardware with very low investment and high reliability.

The systems that allow us to increase security, in the case that concerns us, an access control system to parking lots using technology, using logical systems that limit human intervention and reduce the risk of danger.

Automatic and efficient systems such as the one described above allow us as a society a better way to interact in the current environment, which suggests a minimum social interaction to preserve our health and that of our loved ones.

The development of our article allowed us to acquire better handling of the hardware description language Verilog, to carry out an idea in a practical way with multiple forms of development, given the various tools that the PSoC Creator software has.

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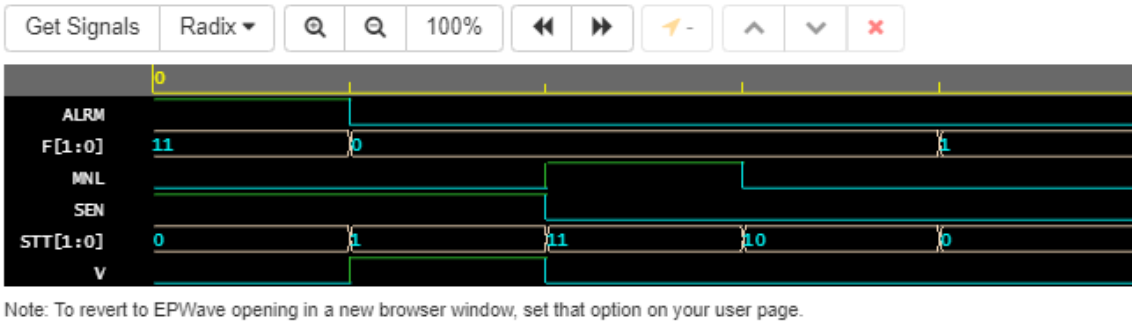
Figure 12

Simulation of module 5.



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Configurable digital PWM for simple projects

PWM digital configurable para simples proyectos

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This paper presents the software implementation of an adjustable PWM (Pulse Width Modulator) prototype, developed in Verilog code, which functions as a training tool at the undergraduate level, or for the development of small projects. At the schematic level, the prototype presents the main module called PWM which integrates three modules (frequency, useful cycle, and display), as a complement to carry out results under the conditions specified in the functional profile. The base module integrates combinational and sequential circuits, i.e. counters, comparators, flip flops, function generators, etc. The final results obtained by simulation show the expected behavior in terms of frequency setting, duty cycle, and display.

Keywords: Digital circuit, hardware description, PWM, Verilog

Este artículo presenta la implementación, en cuanto a software, de un prototipo de PWM (Modulador por Ancho de Pulso) ajustable, desarrollado en código Verilog, que funcione como herramienta de formación en el ámbito de pregrado, o el desarrollo de pequeños proyectos. En cuanto a esquema, el prototipo presenta un módulo principal llamado PWM el cual integra tres módulos (frecuencia, ciclo útil y display), como complemento para llevar a cabo resultados bajo las condiciones especificadas en el perfil funcional. La base de los módulos integra circuitos combinacionales y secuenciales, es decir contadores, comparadores, Flip Flops, generadores de funciones, etc. Los resultados finales obtenidos por simulación muestran el comportamiento esperado en cuanto a ajuste de frecuencia, ciclo útil y visualización.

Palabras clave: Circuito digital, descripción por hardware, PWM, Verilog

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Introduction

Pulse width modulation (also known as PWM) of a signal or power source is a technique in which the duty cycle of a periodic signal (sine or square, for example) is modified, either to transmit information over a communications channel or to control the amount of power sent to a load (Cooper & Stowe, 2018; Zope et al., 2012).

Some machines require partial or variable power. In the past, control (such as in a sewing machine foot pedal) was accomplished by using a rheostat connected with the motor to adjust the amount of voltage flowing through the engine. It was an inefficient scheme since this energy is also lost as heat in the resistance element of the rheostat but is tolerable because the total power was low. While the rheostat was one of several power control methods, a low-cost and efficient power switching adjustment method was still to be found. This mechanism also had to be capable of controlling fan motors, pumps, and robotic servos, and it had to be compact enough to interface with dimmers. The PWM emerged as a solution to this complex problem (Posada Contreras, 2005).

The main advantage of PWM is that the power loss in switching devices is shallow. PWM also works well with digital controls, which, due to its on/off nature, can easily adjust the duty cycle when necessary (Martínez & Gómez, 2007). PWM has also been used in some communication systems. For example, its duty cycle has been used to transmit information through a communication channel or even to control LED lamps in artistic visual schemes. Another application is to send data in an analog way. It is helpful to communicate analogically with digital systems.

The main disadvantage of PWM circuits is the possibility of radio frequency interference. However, these can be minimized by locating the controller close to the load and filtering the power supply (Zope et al., 2012).

Currently, there are many integrated circuits in which PWM modulation is implemented, in addition to other very particular ones to achieve functional circuits that can control switched-mode power supplies, motor controls, thermoelectric element controls, choppers for sensors in noisy environments, and some other applications. Companies such as Texas Instruments, National Semiconductor, Maxim, and others are known for manufacturing this type of integrated circuits (Zope et al., 2012).

For a digital system, it is relatively easy to measure how long a square wave lasts. However, suppose you do not have a digital-analog converter. In that case, you cannot get information from an analog value since you can only detect if there is a specific voltage, 0 or 5 volts, for example (digital values of 0 and 1), with a certain tolerance. Still, you cannot measure an analog value. However, with a digital oscillator, a counter, and an AND gate as a pass gate, the PWM could quickly implement an ADC (Zope et al., 2012).

Reduced costs of power electronic devices, increased reliability, efficiency, and power capacity, and lower development times, along with more demanding application requirements, have driven the development of several new inverter topologies recently introduced to the industry, particularly voltage converters. However, the new, more complex inverter topologies and fields of application are accompanied by additional control challenges, such as voltage unbalances, power quality issues, higher efficiency needs, and fault-tolerant operation, which necessarily require the parallel development of modulation schemes. Therefore, recently, there have been significant advances in the field of DC/AC converter modulation, which conceptually has been dominated for the last decades almost exclusively by classical PWM pulse width modulation methods (Leon et al., 2016).

The PWM technique is one of the most widely used strategies to control the AC output of the power electronic converter (Posada Contreras, 2005). In this technique, the duty cycle of the converter switches can be varied at a high frequency to achieve a low-frequency average output voltage or current (Peddapelli, 2017).

The different PWM techniques considered are Carrier Overlap PWM (CO-PWM), Variable Frequency PWM (VF-PWM), Phase Shifted PWM (PS-PWM), Alternate Phase Opposition Layout PWM (APOD-PWM), Phase Layout PWM (PD -PWM), Phase Opposition Layout PWM (POD-PWM) (Deepa et al., 2017).

Problem Statement

An adjustable PWM is a device capable of generating signals with which it is possible to control the frequency and duty cycle in motor drives, MCU, control-related circuits (PWM attenuation), speed regulation applications, etc. Among the main features of adjustable PWMs in the market are; frequency and configurable duty cycle, among others. However, the frequency range of most commercial devices starts from 1Hz, i.e., there is no adjustable PWM in the market with a frequency range below 1Hz as a starting point with which it can be practiced studiously.

Due to the academic necessity of wanting to control on many occasions experimentally, the energy that is taken to a load or to send information dynamically and under certain specific conditions in a digital circuit and as a consequence of the non-commercialization of PWMs with specific characteristics of operation, the exigency arises to implement an autonomous control system for the control of an adjustable PWM with which it is possible to explore digital circuits to low frequencies.

It is for such reason that this project will develop a sufficient theoretical methodology for the future implementation of an adjustable PWM. In such an adjustable PWM, the student will be able to control and visualize

the frequency range, and the duty cycle will be able to accommodate the PWM settings. Moreover, it will be able to obtain a second output relative to the inverse value.

The following (Fig. 1) is the state diagram of the adjustable PWM. In this case, and according to the logic, there is an initial state that represents the possibility of being able to increase or decrease the frequency and the duty cycle, change between these two states using the Set pushbutton or perform a Reset to the system. Resulting in a signal on display and, at the same time, a signal on the outputs.

The PWM frequency must be configurable between 1 kHz and 10 MHz. For this purpose, two push buttons and a display must be incorporated. One push button should increase the frequency value, and the other should decrease it. The values are to be shown on display. The system must incorporate a display to show general system information, including settings such as this. The increments and decrements must allow the frequency to be set and, at the same time, be functional.

The duty cycle should be controlled with another pair of push buttons, and the information should be displayed. The increments and decrements, in this case, should be every 10% of the maximum value (i.e., every 0.1).

Adjustments to the PWM should be implemented by pressing another push button called SET. All push buttons must incorporate software anti-bounce systems. In addition, the system must have a second output corresponding to the inverse value of the PWM (Q).

Research Method

The design of this PWM is based on the development and implementation of combinational, sequential circuits in which four modules are included and programmed; a display module, a frequency inverter module, and a duty cycle turner module.

The main variable PWM module contains the frequency, duty cycle, and display modules, it has the function of processing and integrating all the signals according to the frequency, and duty cycle settings entered and delivering two signals, one signal according to the configuration, and the other signal is the same but negated (Figs. 2 and 3).

The frequency module (Fig. 4) receives the increment and decrement signals from 1 kHz to 10 Mhz and delivers a signal to the duty cycle module according to the increment or decrement selection and delivers a signal to the display module to visualize the selection. If the frequency module sends a signal to the duty cycle module indicating an increment, that signifies that the clock must decrement; if it sends a signal to the duty cycle module indicating a decrement, it signifies that the clock must increment.

In general terms, the frequency module works as a divider, which using comparators is constantly comparing the present state of the clock signal through the maximum frequency obtained of 100 MHz to obtain more minor frequencies, utilizing a clock and a counter which counts the rising edges of the 100 MHz signal, according to the setting, this makes it change the low signal to a high signal, for example for a frequency of 1 kHz (minimum frequency supported) we have:

$$R = \frac{100MHz}{1KHz} = 100000 \tag{1}$$

This result is divided in two:

$$R = \frac{100000}{2} = 50000 \tag{2}$$

This means that we must create a counter that counts up to fifty thousand edges, changes from a low signal to a high signal, counts the period for a 1 kHz signal, and restarts. The approach we will use is to look at the maximum period observed and search for that in all possible starting periods.

The frequency variator integrates, of course, anti-rebound modules that will enable the elimination of the fluctuations created by the push buttons. A conditional was placed where a variable changes its value when the pushbutton is pressed. That is when it is in LOW. After the variable has its new value and the pushbutton is released, the desired action is performed in the module.

The duty cycle is the ratio of how long each cycle is HIGH versus how long it is LOW. So to change the duty cycle of the PWM signal, we would need to divide the time of each cycle by something other than 50/50. So, for example, to increase the duty cycle of the signal we have been working with, too, say, 75%, we need to make the HIGH delay time longer than the LOW delay time.

The duty cycle module (Fig. 5) is configured to receive, on the one hand, the decrement and increment signal of the desired cycle and the output signal of the frequency module that will serve as the base signal for the adjustment of the duty cycle, with the adjustment of the cycle basically what is intended is to know what percentage of the frequency signal is to be used.

The internal structure of this module contains anti-reboot, comparator, and counter sub-modules. The display module (Fig. 6) allows the visualization of the frequency, duty cycle, and set and reset signals. It receives the signal from the frequency and duty cycle module, indicating the frequency and duty cycle range in current status. The structure of the display module is composed of four multiplexers, gates, and memories.

Results and Discussion

Simulation results are obtained by ModelSim software. The Verilog codes are synthesized in Xilinx ISE, and the simulation is carried out in ModelSim, which provides

Figure 1

State diagram.

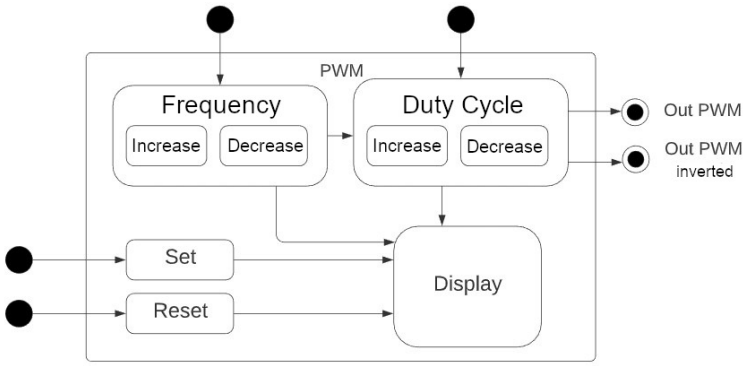
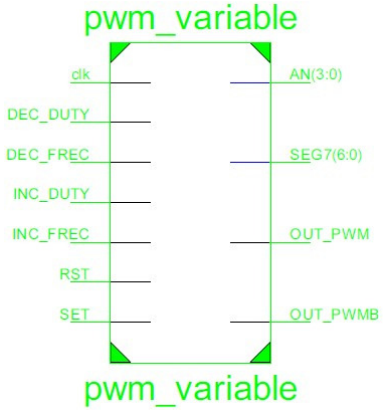


Figure 2

PWM module (schematic diagram).



the design output developed for each system's operating conditions.

Once the programming and synchronization of all the modules in the variable PWM system were done, the frequency test at 1 kHz and 10 MHz and the duty cycle increment and decrement test were performed. The simulation results are shown in Figs. 7 to 10.

Conclusion

This project is the development of a PWM module of low cost and wide versatility as a working tool for students in the area of electronics and digital control of electrical machines. The academic approach of the tool is supported by a fast, simple, and economical implementation, suitable for undergraduate students. The objective is to describe and implement the system using Verilog, evaluating its performance through simulation. The software adjustable PWM prototype is developed according to the conditions indicated in the design profile. From the performance tests, it was determined that the system operates as expected. However, at low frequencies, there is the possibility of having an error in thousandths of a second concerning the period of the signals, which is within the expected range of operation of the system. The prototype should be complemented with a system that guarantees its safe operation considering its use by students.

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Figure 3

State diagram (block detail).

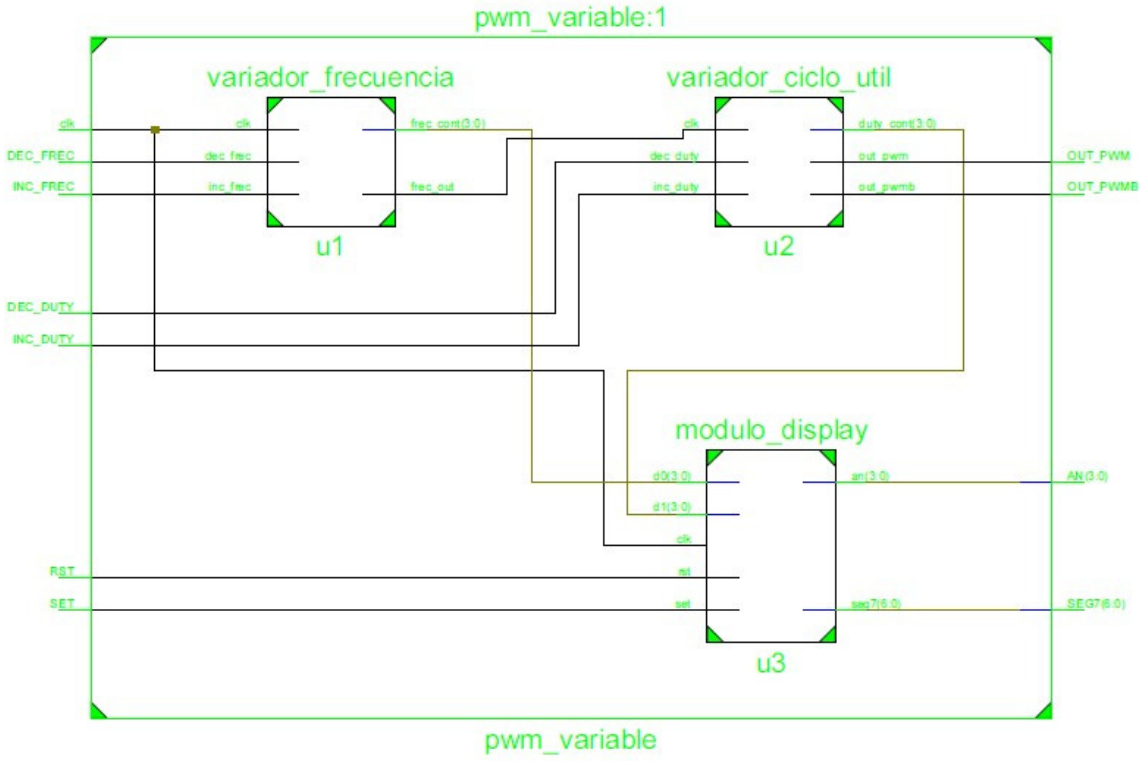

Figure 4

Frequency module.

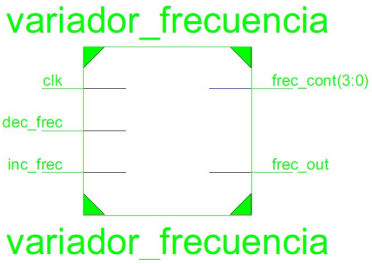

Figure 5

Duty cycle module.

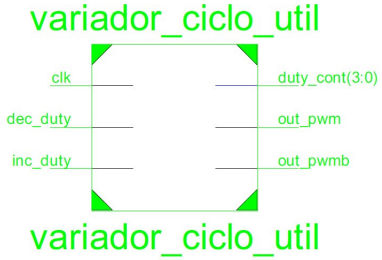

Figure 6

Display module.

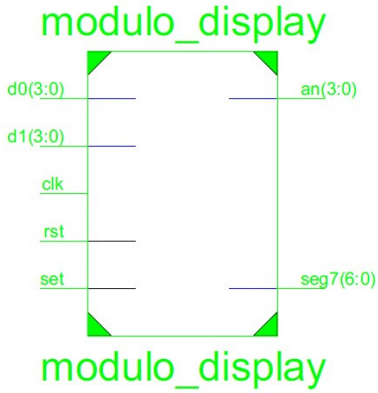

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Figure 7

Frequency at 1 kHz.

Figure 8

Frequency at 10 MHz.

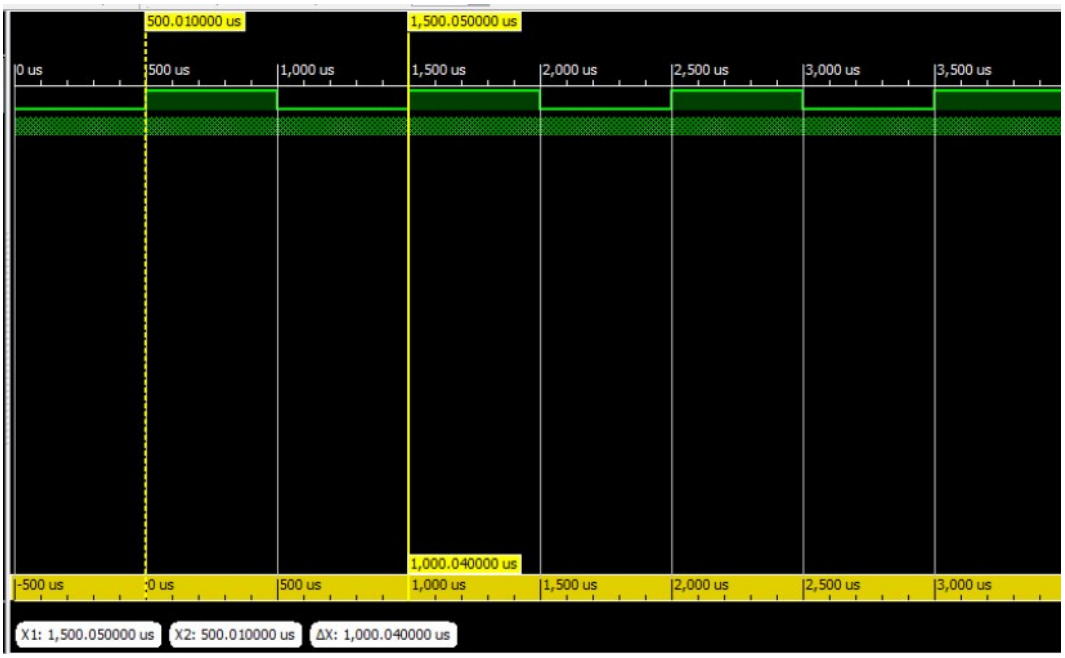


Figure 9

Increase of duty cycle.

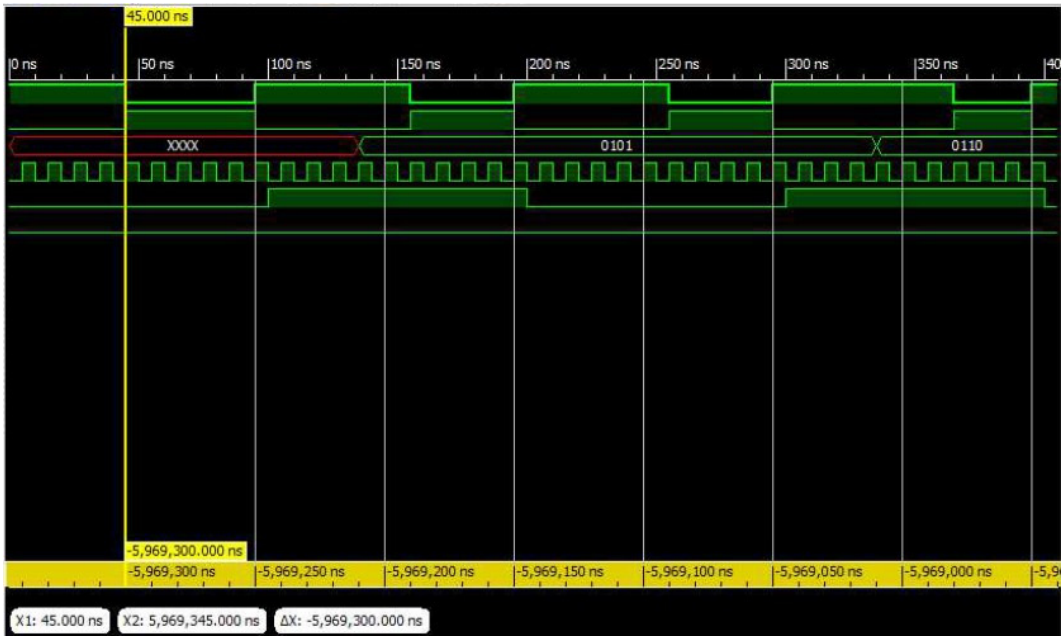
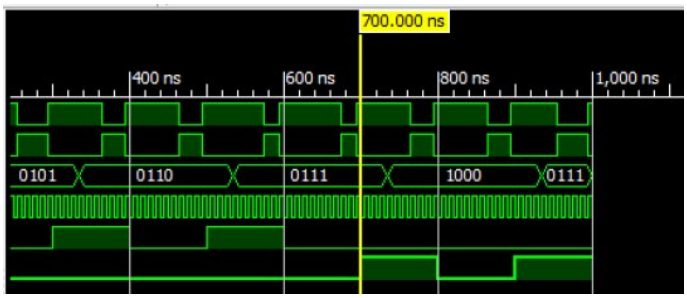


Figure 10

Decrease of duty cycle.



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