# "Optical sensor EIB/KNX gateway".

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## ABSTRACT

Nowadays, there are some special buildings like for example power or chemical plants, where conventional electronic sensors cannot be used as they are exposed to explosive environments or due to the presence of either electromagnetic interferences, or chemical or mechanical disturbances. Because of that, those sensors cannot operate and monitor correctly the target parameters. In these cases, the use of optical fiber sensors is a valid alternative due to their passive nature, immunity to electromagnetic interference, small size and light weight, avoidance of ground loops, capability of responding to a wide variety of parameters, durability, resistance to harsh environment, remote operation or capability of multiplexing among others advantages.

On the other hand, the control and monitoring of that kind of buildings are necessary and very important, so Intelligent Building systems as EIB or Konnex should offer a solution. This work describes the development of a new gateway consisting of an EIB module intended to connect optical fiber sensors directly to the bus. That is, a new input module where the optical signal from this kind of sensors is analyzed and translated to the EIB communication protocol.

The first prototypes include four optical inputs (FC/PC and SMA optical connectors) and is equipped with different photodiodes to receive optical power at 1310nm and 1550nm (standard telecommunication wavelength). Furthermore, the module also includes two optical sources at 1310nm and 1550nm to illuminate the optical fiber sensors and an optical coupler if the optical sensors use a reflection scheme. In order to adapt the optical signal to the EIB bus signal the module also includes a BIM.

In short, a new opto-electronic input module for EIB system has been designed for its application in special buildings where traditional sensors cannot be used due to the hostile environment.

## KEY WORDS
EIB gateway, EIB input module, optical sensors, BIM, special buildings.

# 1.- Introduction

All around people are living things that sense and react to their environment in sophisticated ways. As structures have become more complex and are being required to perform ever more difficult missions, there has been an ever-increasing need to develop "intelligence" into them so that they can sense and react to their environment. Nowadays, nobody surprises reading about artificial intelligence and everyone knows what it is. Examples include buildings that can sense, react and survive earthquakes, and spacecraft that can sense and repair damage autonomously. To perform this successfully, a "nervous system" is required in a manner analogous to those of living things: sensing the environment, sending the information to a processor unit and reacting appropriately [1-2].

The number of parameters to measure and monitor inside buildings is increasing day by day. There exit some traditional parameters that are always monitored as the temperature (inside and outside the building), the presence of some gases, the possibility of fire, etc. On the other hand, there are many other magnitudes that are starting to be measured and monitored as the relative humidity in the air, the luminosity, the pressure of the atmosphere, or even the electromagnetic field.

Traditional electronic sensors can measure all this parameters but they present some disadvantages when the number of sensors in the same building or network is very high. Besides, there are some special buildings as power or chemical plants, where this kind of sensors cannot be used as they are exposed to explosive environments. Also in presence of electromagnetic interferences, or due to chemical or mechanical disturbances, those conventional sensors cannot operate correctly.

In order to solve these inconveniences, there is an emergent technology called "optical fiber sensors". These sensors are a valid alternative due to their passive nature, immunity to electromagnetic interference, small size and light weight, avoidance of ground loops, capability of responding to a wide variety of parameters, durability, resistance to harsh environment, remote operation or capability of multiplexing among others advantages [3].

Once the sensor network problems are solved, this kind of especial buildings needs a powerful Home Automation System capable of integrating the sensor network into the management and control system of the building obtaining an Intelligent Building. The EIB/KNX system offers one of the most powerful standard related to Intelligent Building especially designed to its implementation in large buildings [4].

This paper describes the development of a new gateway consisting of an EIB/KNX input module to connect optical fiber sensors directly to the bus.


# 2.- Optical Fiber Technology

The development of the optical communications using fiber optic as the transmission guide meant a world revolution due to their advantages versus other transmission guides as copper cables. The fast development of this new technology and its fast implementation in the communications all over the world generated the creation of many research groups in this field. So, as fiber optic technology has been

under study for more than 25 years, many different optical fiber devices have been developed as couplers, sensors, polarization controllers, acousto-optics modulators, and filters, to mention only a few [5-6]. The research of optical fiber sensors have generated the development of optical fiber sensor networks and their implementation in smart structures as Intelligent Buildings.

These devices present several advantages:

***Immunity to electro-magnetic interference***: due to the passive nature of the fiber optic, these sensors are immune to electromagnetic interference and they do not generate them. Because of that they are very useful in especial environments.

***Small size:*** optical fiber sensors present a small size due to the dimensions of the fiber ($\mu$m of diameter). With this advantage, these sensors can measure some parameters in especial places where traditional sensors cannot be implemented.

***Low weight:*** optical fiber sensors present a low weight due to the nature of the fiber.

***Passive nature:*** due to this characteristic, optical fiber sensors are very interesting in biomedical applications. They present the ability to function without any interaction with electromagnetic fields.

***Wide Band Width:*** the band width of the optical fiber is very useful for the application in smart structures as the data network can be integrated in the sensor network implementing only one optical network.

***Low Losses:*** of attenuation, these sensors may cover long transmission distances without loosing the transmitted information from the measuring point to the processing unit. Besides, this characteristic allows the multiplexing of many optical fiber sensors in the same network.

***Possibility of integration inside materials:*** the characteristics of the optical fiber sensors allow the possibility of integrating them inside materials in order to monitor and test in real time the state of the material and its response against variations in the environment.

The optical fiber is also remarkably strong, elastic, and durable, and fiber optics has found its place as an instrumentation medium for addressing smart structures where the sensor must tolerate the environment to which the structure is subjected and therefore be immune to large physical strain excursions, substantial temperature excursions, and often a chemically corrosive environment.

Fiber optic technology has enabled the nerves of the system to be realized. Using hair-thin glass fibers as information carriers, sensors can be built directly into fibers with no increase in overall size. This fiber optic sensor system may be embedded into structural materials resulting smart structures with built-in nervous systems capable of measuring strain, pressure, temperature and many other key parameters.

The trends of fiber optic smart structures are illustrated by figure 1 [7]. In the early 1980s few components were available and they were expensive. This situation resulted in fiber optic smart structures being used in only a few niche markets where their advantages were overwhelming.

By 1990, the number of components had increased dramatically. In the same time period, new components, such a fiber couplers, wavelength division multiplexing elements (very important for fiber optic smart structures) and integrated optical devices became commercially available. The result was that many more fiber optic

smart structures were developed, penetrating such markets as inertial rotation, power system monitoring, and manufacturing and process control.

As it is shown in figure 1, during this new century, it can be expected that many more components, integrated devices, pigtail light sources, etc. will be available at low cost. Besides, devices based on Bragg gratings are leading fiber optic sensor networks and their applications in smart structures. The result is being the widespread proliferation of fiber optic sensors and their use in industrial control systems and the rapidly evolving area of fiber optic smart structures that includes health maintenance and diagnostic systems for aerospace vehicles and civil structures.
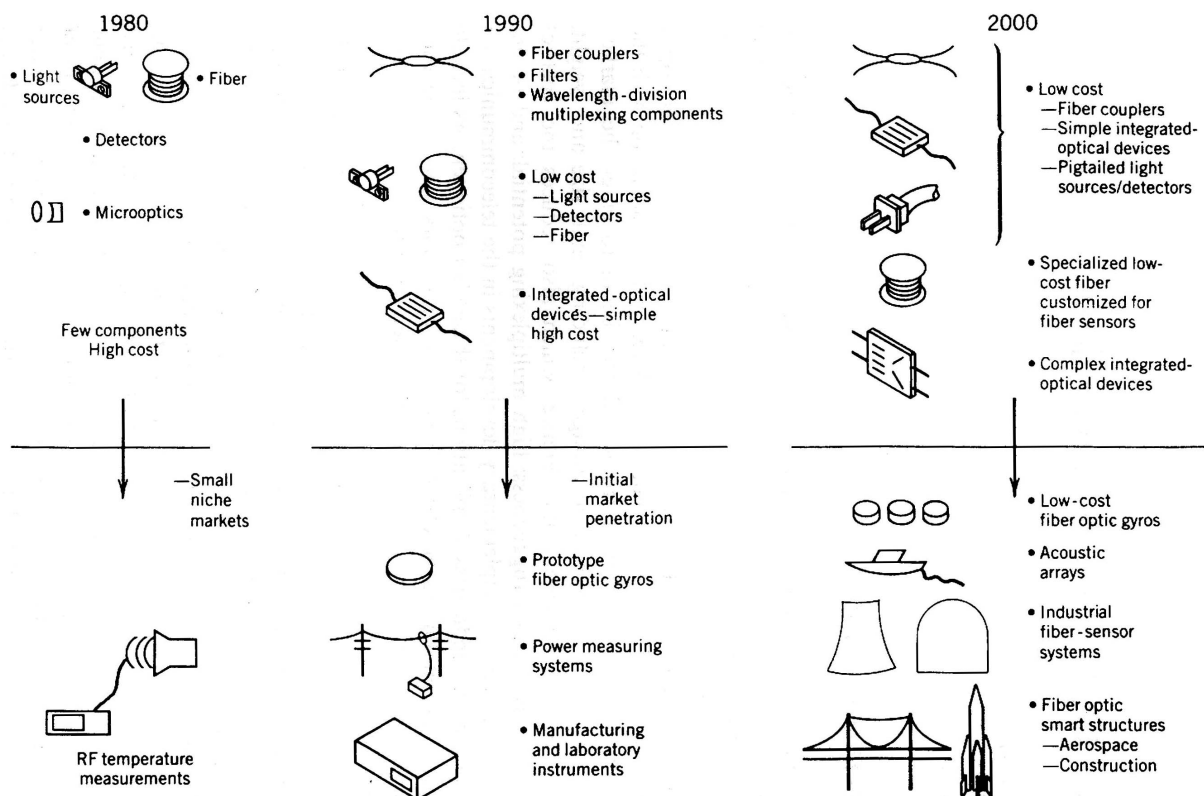


**Fig. 1.- Trends of fiber optic smart structures**

## 3.- Optical Fiber Sensors

There are different optical fiber sensor classifications attending to the measured parameter, the topology of the sensor, the nature of the transduction or the light-parameter modulated. The last one is the most used, so according to the parameter of the light that is modulated by the measurement, optical fiber sensors can be classified into four types:

***Intensity modulated sensors:*** the measured parameter modifies the intensity of the light reaching the detection block. This kind of optical sensors can be divided into two different main groups:

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- *Reflection configuration:* the parameter is detected at the end of the optical fiber and measured reading the reflected optical power.
- *Transmission configuration:* the parameter is detected at some point in the fiber and measured reading the transmitted optical power.
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**Spectroscopic or wavelength modulated sensors:** the measured parameter modifies the spectrum of the light reaching the detector. These sensors are actually the most popular due to the fiber Bragg gratings: the most representative sensor of this type. They have reached a high commercial deployment due to the simplicity of the transducer. Their main problem is that they require an expensive and complex terminal equipment.

**Phase or interferometric sensors:** the measured variable causes a phase modulation of the light at the transducer element.

**Polarimetric sensors:** the polarization of the light is modulated by the measurement.

The kind of sensors selected for this work is the intensity modulated sensors as this type of sensors is one of the simplest, cheapest and more employed, although their sensitivity is usually much lower than that obtained with, for example, interferometric sensors. Besides, the versatility of this kind of sensors allows them to measure a great number of parameters in many different environments. The main inconvenience of this type of sensors is that as there are many different optical fiber sensors the optical power range to cover is very wide. This fact is due to there are sensors that work around –20dBm of optical power while there are many others that work in a range around –50dBm.


# 4.- Optical Sensor EIB/KNX Gateway

The designed gateway has been built in collaboration between two Universities: the Public University of Navarra and the Polytechnic University of Cartagena both EIB Scientific Partnership. The main scheme of the system is shown in figure 2.

As can be seen in the figure, the first prototypes include four optical inputs with FC/PC and SMA connectors and are equipped with different photodiodes (model G8194-22 with FC connector and similar ones) to receive optical power at 1310nm and 1550nm. Besides, the module also includes two optical sources at 1310nm and 1550nm. In order to adapt the optical signal to the EIB/KNX bus signal the module includes an opto-electronic interface and also microcontroller hardware with a BCU.
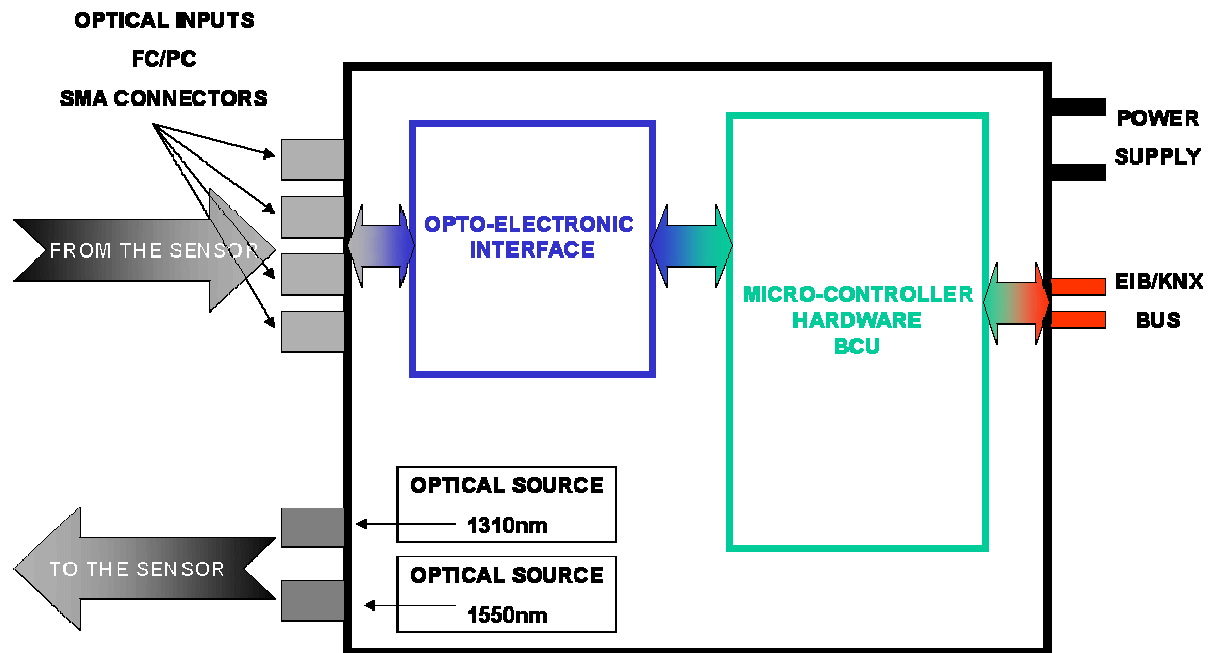
**Fig 2.- Scheme of the optical sensor EIB/KNX gateway**

The development of this new device can be divided into four different parts:
- Design and implementation of the optical fiber sensor for their application in Intelligent Buildings.
- Design and implementation of the opto-electronic interface.
- Design and implementation of the micro controller hardware.
- Design and implementation of the software.

These parts of the research project are analyzed and studied in the following paragraphs.

## 4.1.- Design and implementation of the optical fiber sensors for their application in Intelligent Buildings.

During the last ten years, the Public University of Navarra has been researching in the optical fiber sensors technology field developing many different sensors for detection several key parameters in buildings such as temperature, relative humidity, gases, etc.

As nowadays there is an increasing interest in developing optical fiber sensors for detection of gases in specific applications as in the chemical industry or in especial Intelligent Buildings, a sensor for the detection of ammonia was fabricated for the initial prototype.

This optical fiber sensor uses a vapochromic material, lutetium bisphthalocyanine (LuPc2), which refractive index changes with ammonia in combination with a standard 1.3 $\mu$m single-mode optical fiber pigtail (core and cladding diameters of 9.4 and 125 $\mu$m respectively) which ends were cleaved. By using the Langmuir-Blogett (LB) technique, lutetium bisphthalocyanine films are

deposited on one of the ends of the fiber. The other extreme is connected to an optical coupler. So, the ammonia sensor works in a reflection way. The set-up was completed with an optical source (also included in the EIB/KNX optical gateway) to generate the interrogating signal. The information of the sensor is connected to optical gateway to measure the received modulated optical signal.

The behavior of the sensor has been studied for different wavelengths (1310nm and 1550nm) in the telecommunication windows, with the associated advantages this fact implies, and also for different concentrations of ammonia.


## 4.2.- Design and implementation of the opto-electronic interface.

The main objective of this part of the EIB/KNX optical gateway is converting the optical signal into an electrical signal to send the information received from the optical sensors to the micro-controller hardware.

As it has been explained before, the first problem in the design of this interface was the desirable wide optical power range at the optical inputs. In order to cover as many optical fiber sensors as possible, a wide range between –15dBm to –60 dBm was selected. According to the input electrical levels of the micro-controller hardware module, the electrical signals at the output of this interface might be enclosed between 0 and 5V. Due to these two starting points (the input optical range and the output electrical range) and to the characteristics of the selected photodiodes, it was necessary to define two different amplifier stages: a pre-amplifier module and an amplifier module. Both stages must provide at the highest optical power at the input of the gateway (-15dBm) a total gain of 20, giving 5V at the output of the interface. On the other hand, at the lowest optical power at the input of the gateway (-60dBm), both stages must provide a total gain of 100000, giving 0V at the output of the interface.    The preamplifier module consists of four amplifiers (one for each photodiode or optical input of the gateway) model INA111 with a variable gain between 1 and 10000. This variable gain of each amplifier is electronically controlled by a digital potentiometer model MAX-4051. These four digital potentiometers received orders from the final user via ETS2 as it will be explained later. The output of the four amplifiers is connected to an analog multiplexer that provides only one output to the next amplifier stage. This device is controlled by the PIC of the following stage which will select the desired input channel. This analog multiplexer was included in order to reduce the final cost of the device removing three amplifiers in the second amplifier stage.

The amplifier module consists of only one amplifier integrated circuit (INA111) with a variable gain between 1 and 10000 controlled by a digital potentiometer model MAX-4051 and connected to a PIC model 16F876. This PIC controls both the variable gain of the opto-electronic interface and the analog multiplexer.

This device has been selected because it can exchange information with the micro-controller hardware module via the Physical External Interface (PEI) through a serial communication port in order to control the amplification modules with ETS2. This PIC includes five 10-bit A/D converters, one of them to convert the analogue signal received from the multiplexer and the other four get free. Figure 3 shows a schematic diagram of this interface.
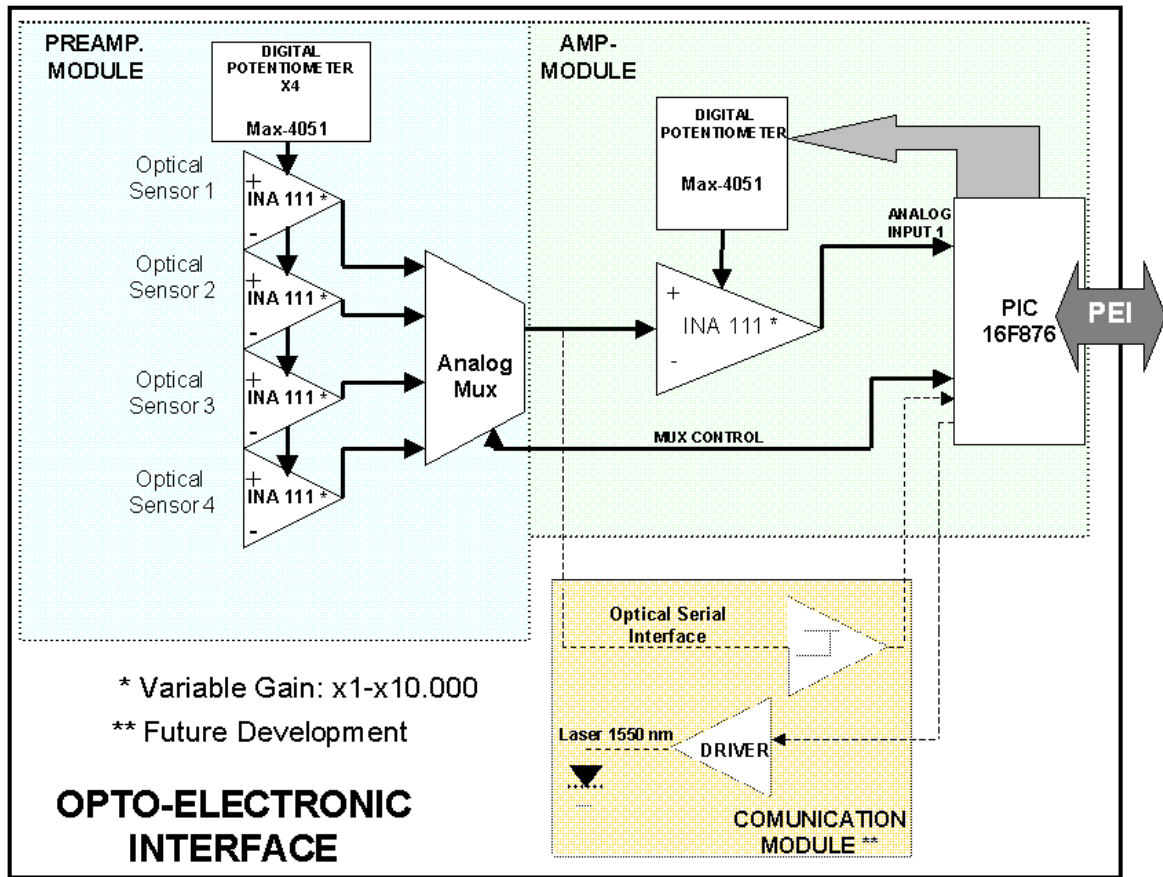
**Fig 3.- Schematic diagram of the opto-electronic interface of the optical sensor EIB/KNX gateway**

This interface is designed to incorporate in a future version a communication module to use this device to optically connect two different EIB/KNX installations when required. It also could be used to connect two modules of the same EIB/KNX installation when the distance between then or the presence of electromagnetic interferences make it convenient. The communication module will include an optical serial interface and a driver for the laser module.

## 4.3.- Design and implementation of the micro controller hardware.

This part of the system is very important as it is where the software is loaded and is the real interface with an EIB/KNX installation. Its block diagram is shown in figure 4.

This interface includes a Bus Interface Module M112 using a 68HC11 microcontroller. The ROM of this device contains the EIB/KNX system software. This module includes all the buffers necessary to send and receive EIB/KNX telegrams. The interface also includes the following components:
- An external EEPROM where the application program, the PEI driver, the group address and the EIB/KNX parameters are stored.
- A volatile RAM with the temporally variables of the program.

- An address latch to filter data and addresses. It is also used as decoder to select the type of necessary memory in the microprocessor.
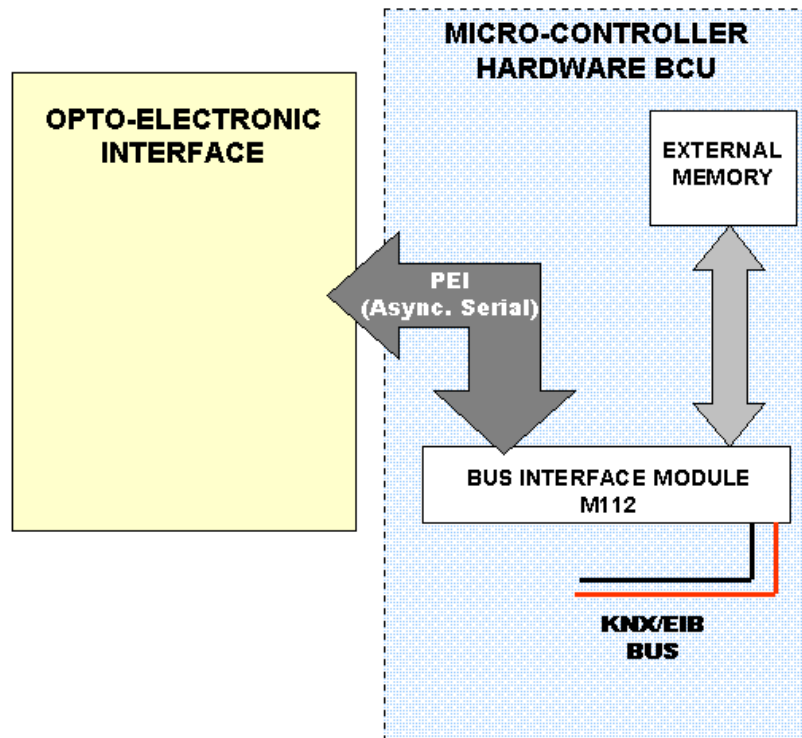


**Fig 4- Block diagram of the micro-controller hardware BCU**

This module is connected to the opto-electronic interface via the PEI. As it has been explained before, the opto-electronic interface transmits the adapted information received from the optical fiber sensors to the micro controller hardware. These signals are adapted to a fixed level from 0 to 5V.

The application program and the driver for the Physical External Interface (PEI) have been programmed in C language using the EIB Integrated Development Environment (EIB - IDE). The driver of the PEI is used to configure the serial port for asynchronous communication at 19200 bauds. On the other hand, the application program consists of four byte type objects.

These objects are employed to send the obtained values in each channel of the optical sensors EIB/KNX gateway received from the opto-electronic interface.

**4.4.- Design and implementation of the software.**

The software of the EIB/KNX optical gateway has been developed using the Manufacturer Tool of the ETS2 software. Four byte type objects have been created, one for each input. The application program has been designed to check and store the state of each optical sensor periodically. Figure 5 shows the general menu for the parameters using ETS2 where the user may configure these two above mentioned options.
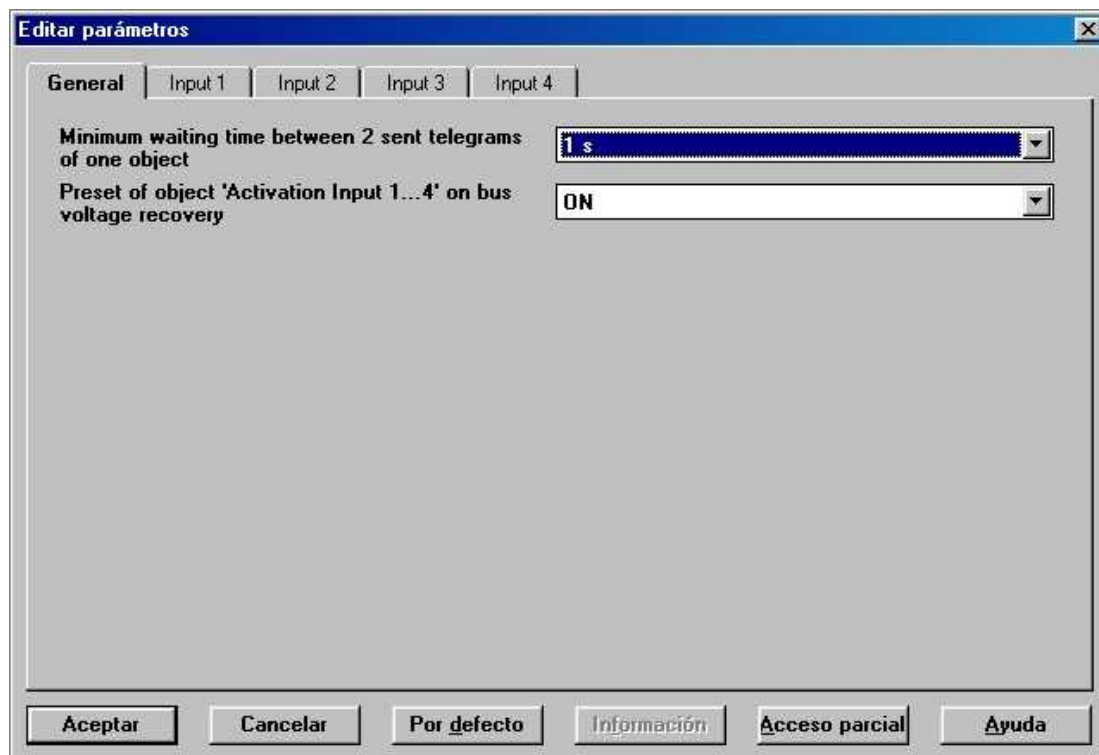
**Fig 5- General menu for the parameters**

Figure 6 shows the menu of the parameters for each optical input using ETS2 where the user may select the desired parameters.
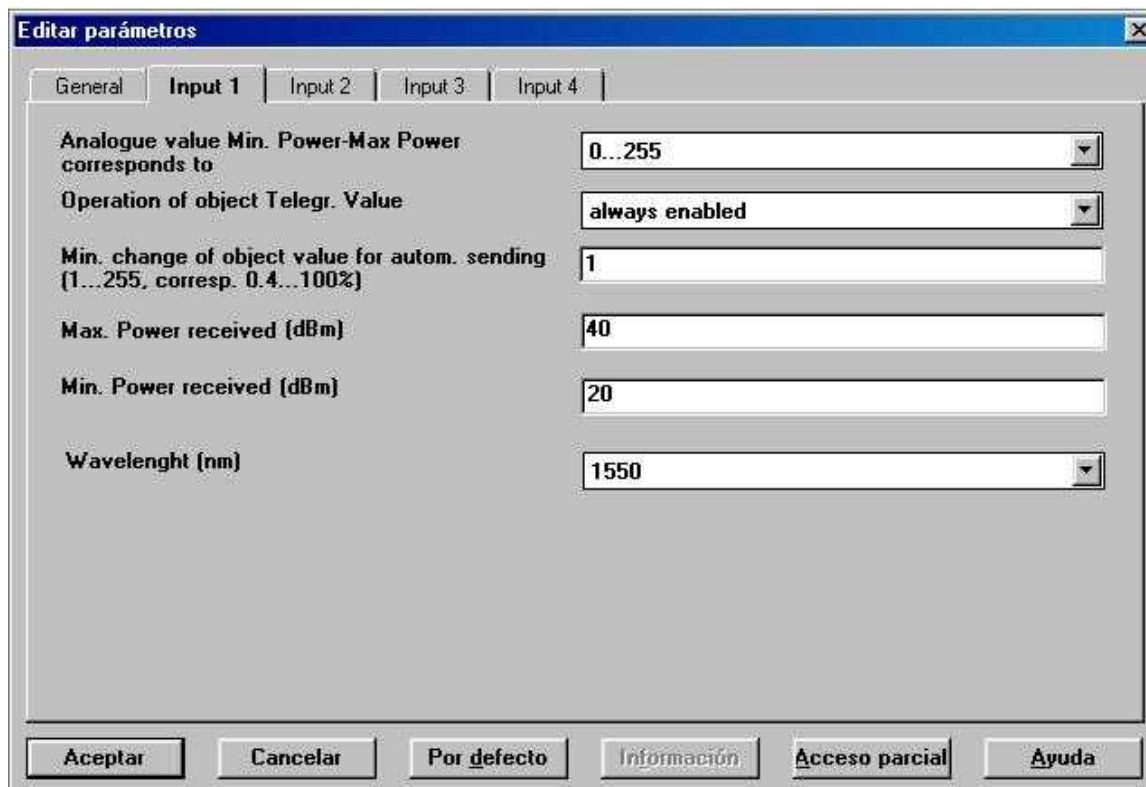


**Fig 6- Menu of the parameters for each optical input**

As can be seen, the software also includes the possibility of selecting the range of the optical power that must be delivered to each input of the EIB/KNX optical gateway depending on the optical power of each sensor. This selection can be done using the appropriated component parameters between the options offered in the program:

- Minimum optical power at the input.
- Maximum optical power at the input.
- Operating wavelength.

The control of the optical power range at the input is established following this sequence:

1.- The user select the desired range in the parameters options.

2.- ETS2 transmits this parameter to the BIM in the EIB/KNX optical gateway.

3.- The BIM sends this information to the PIC through the serial transmission port via the PEI.

4.- Finally, the PIC controls the digital potentiometers to obtain the selected optical power range at each input.

## 5.- Conclusions

In this paper a new EIB/KNX device has been presented. It consists of a optical sensors input module. The main objective is integrating this type of sensors in especial buildings with concrete necessities where traditional sensors cannot be used due to the hostile environment.. This work has been done under the collaboration of two research groups from two different Universities: the Public University of Navarra and the Politechnic University of Cartagena.

The first prototypes include four optical inputs with FC/PC and SMA connectors and is equipped with different photodiodes to receive optical power at 1310nm and 1550nm the most used communication wavelengths. The first tests have been done with an ammonia optical fiber sensor obtaining successful results. Besides, actually the work is not finished and a new future line has been opened: the use of this new optical gateway as a transmitter/receiver of optical communication for EIB/KNX installations.

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