1 Abstract

OSELIN ALBANO d.i. a company of 3 people, of which 1 is involved in electronics, develops and manufactures turn key electronic control products for industrial and domestic gas burners. They supply several important Italian gas burner manufacturers.

The company has traded since 1982, but, until now its products have been based on the use of discrete analogue devices. This technology has limited the adaptability of the current products, and has been a significant factor in restricting the Company's competitiveness and growth.

The objective of this Application Experiment was to develop a cost effective solution to perform the functions of gas burner ignition control and flame modulation, while greatly improving the product's overall performance. The use of an integrated solution provides commercial advantages through product size, certification, and production cost reductions. Reliability is improved , auto-test features are incorporated and the repeatability and long term stability of performance are improved in the new design. It should be mentioned that the product's reliability and safety are major requirements in this application area.

A microcontroller was preferred because of its flexibility and straight forward customisation, key issues when dealing with commodity products where fast change requests are a regular requirement from customers.

The development of a company in-house microcontroller design capability will also enable the transfer of this technology to other products in the company's product portfolio, with subsequent sales and employment growth.

The total cost of the application experiment was 35 kECU and it was completed in 6 months.

The production cost saving achieved with the new product is 12% and the payback period can be estimated at 4.5 months after the beta test phase. The Return on Investment (ROI) is anticipated to be 400% over the 4 years product life.

One of the most important lessons learnt is that it is important to recognise that the initial specifications should be clearly defined. A little more time spent on the specifications' definition would have avoided later delays due to modifications which were required during the design phase.

It is also very important to choose a subcontractor who is prepared to support closely the First User during the whole design cycle.

2 Company name and address

OSELIN ALBANO d.i.
via Rivoli, 36 bis
10090 Rosta (TO)
ITALY

3 Company size

Number of employees is 3, of which 1 is involved in electronics.

The person involved in the AE, Mr. Albano Oselin has spent 34 years in design and test of discrete component boards for boilers and thermal appliances working as technical staff for many companies in the sector. In 1982 he founded OSELIN ALBANO d.i., where he has used his previous experience to develop and sell analogue controls to more than 20 important Italian manufacturers.

Total sales in 1996 accounted for 250 kECU.

While Mr. Oselin has a good experience in analogue design using off the shelf components, he has never used microcontrollers or more advanced electronic technologies.

4 Company business description

The company OSELIN ALBANO d.i. was founded in 1982 for the engineering of custom electronic designs. The activity moved soon towards the development of turn key products carrying on the complete production cycle up to testing of the assembled and packaged prototype.

Activities are performed in two sites, one devoted to PCB mask design and CAD, while the other is the hardware laboratory and is mainly concerned with design and prototype test. Both laboratories have measurement equipment used to assure the quality of both design and production. Some of the preliminary reliability tests like burn-in and lifetime cycles are performed internally with ad-hoc developed automatic test equipment (ATE).

All the product development phases are covered, from the specifications definitions with the customer to the final prototype testing and assessment.

The company’s products include boiler controllers, home and car anti-intrusion systems, special controllers for vehicles, radio remote controls for all frequencies and controllers and actuators for industrial compressors.

The following table shows the proportional turnover achieved by the different products.

Main company products and their turnover share	
Boiler controllers	60%
Remote controllers	10%
Solar domestic hot water controllers	10%
Other OEM appliances	20%

The company is applying for ISO 9002 certification.

5 Company markets and competitive position at the start of the AE

The European market for boiler controllers is a captive one where the major boiler manufacturers develop their own controllers in house. Examples are Junkers, Vaillant (D), Chaffetau and Maury (F) who sell more than 600,000 units per year each. Oselin with less than 6.000 units per annum has a negligible share of this market.

In the National market the situation is the following:

- the company gains importance for the domestic hot water controllers where it supplies big names as JOANNES-FINTERM who covers about 7% of this market.
- the market of the national domestic wall boilers producers is shared as follows[1]:

BERETTA	30%
FERROLI	27%
IMMER GAS	10%
SAVIO	6%
ECOFLAM	6%
Others (including FINTERM)	10%

The major Oselin competition, in the target market, estimated from company published material is shown in the following table. It should be noticed that the reported production units are absolute figures not distinguishing the target market (both domestic and European).

Competitors

Company	Controllers/year
BRAHMA	500,000
INECO	250,000
HONEYWELL (within the whole European market)	1,000,000
SIT	200,000

Oselin with less than 6.000 units per annum has a small market share here also. The company supplies about half of Finterm boilers controllers, therefore its domestic market share can be estimated about 2%

The major technology exploited by the above companies is traditional through-hole PCB with very low cost substrates (CEMM 1) and some thick film devices. Design techniques are always analogue. Only a few controller suppliers use microcontroller technology and, to the best of our knowledge, none of them integrates the ignition control and flame modulation functions.

The Italian market on the company's field is divided into the following main categories

1. general electronics equipment manufacturers that deliver their catalogue controllers to gas burner manufacturers (Brahama, Honeywell, Landis & Gyr, RV, Ineco, Danfoss, Oselin);

2. general electronics equipment manufacturers that produce controllers for gas burner tailored to gas burner manufacturers' need (Brahama, Ineco, Beretta);

[1] Data extracted from the ads of the companies.

3. gas burner manufacturers that produce in-house the controllers for their equipment (Leblanc, Vaillant);

4. general manufacturers that assembles the control panel of gas burners for gas burner manufacturers.

As was mentioned before, the market is very fragmented and cluttered with vary small companies competing using very low end technologies. A technological evolution is the key to move our market share towards a more high end market where these competitors presently have no room. Therefore our main barrier is technological.

With the new product, the First User aims mainly:

- to consolidate its present position and to expand as provider for as many as possible gas burner manufacturers (position 1 and 2 on the list above);
- to enter the market of providers of the third category of the list above.

Our main customer for the domestic boiler controller is currently JOANNES Finterm a medium size burner manufacturer located in Rivoli (TO) which has about a 7% share of the National market.

It should be noticed that JOANNES has been recently taken over by Lamborghini, an important Italian group, therefore the new product perspectives are even better

6 Product to be improved and its industrial sectors

Industry sectors: EN (Burners, and Boilers for domestic usage Prodcom Code 2921)
IC (Electronic components and subsystems PRODCOM CODE 3210)

The ignition control is the core of the burner control system. The block diagram is represented in .

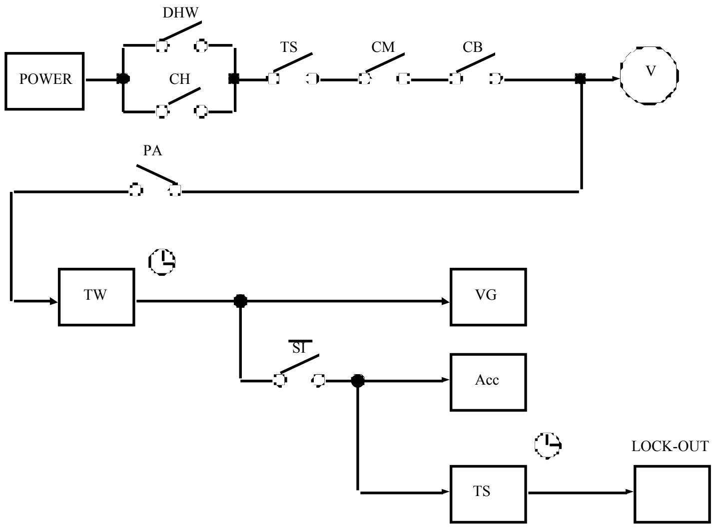


Figure 1

An ignition procedure can be driven by either a central heating (CH) or a domestic water (DHW) request. Under control of the safety thermostat (TS), the environmental thermostat (CM), and the lock-out danger condition (CB), the procedure starts with a ventilation cycle by activating the fan (V) and checking its correct operation via the pressure sensor PA. A timer (TW) is then enabled and the gas valve (VG) supply is connected and the ignition is activated (ACC). If no flame appears in 10 seconds, the valve supply is disconnected and the controller enters the safe lockout state.

The old product mounted in a front panel

The flame modulation main function is the thermostatic control of the burner. The block diagram is represented in Figure 2.

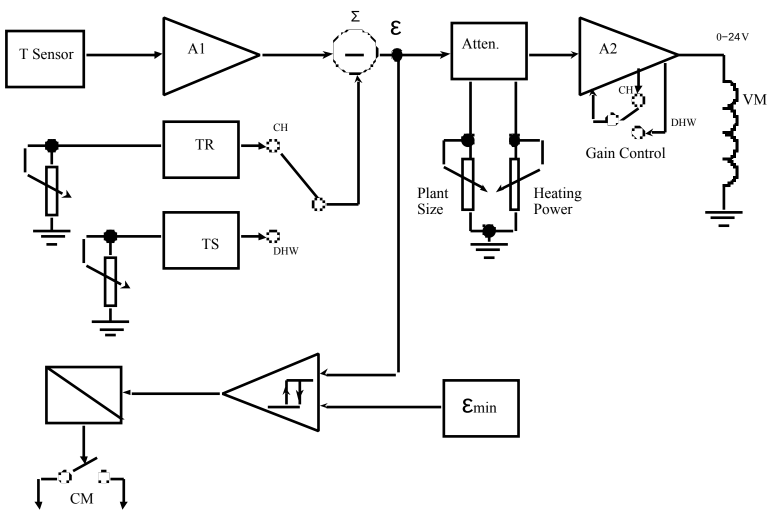


Figure 2

The main input is the temperature sensor (T Sensor) that measures the water temperature. The other input is implicit in the block diagram and is the type of regulation: domestic hot water (DHW) or central heating (CH).

The outputs are:
VM is the modulating valve of the burner. It is used for dynamically adjusting the power of the flame CM is the OK feedback for the ignition control block. When active it means that the water needs heating.

The flame modulation controller is a conventional feedback loop where the burner temperature, sensed by a suitable temperature sensor (PTC or thermocouple), is compared with a preset temperature. The error is then amplified with a gain depending on the size of the environment to be heated and the thermal features of the used fuel and the solenoid valve is regulated accordingly.

An hysteresis comparator supervises the ignition system according to the heating request (CH or DHV).

The main technical features of the flame modulation block are:

- flame intensity modulation;
- single temperature sensor.
- the possibility of independently setting the nominal temperature for central heating and for domestic warm water supply;
- manual adjustment of burner flame maximum intensity and regulator sensitivity according to gas supply caloric power (liquid gas or natural gas supply);
- manual adjustment of flame maximum heating power according to the size of the heating plant, thus keeping the burner ignition duration within an acceptable range;
- toggle small duty-cycle operation protection that ensures a minimum burner idle time before a re-ignition is allowed (typical 2 minutes).

Environmental conditions are specified in the following European recommendations and norms.

Operation conditions are mainly:

- EN 298 – automatic gas burner control systems for gas burners and gas burning appliances with or without fans
- EC council directive 89/336/EEC of 03/05/1989
- EC council directive 92/31/EEC of 28/04/1992
- EC council directive 93/68/EEC of 22/07/1993
- EC council directive 73/23/EEC of 19/02/1973
- EN 50081-1 1991
- EN 50082-1 1991
- EN 60555-2 1987
- EN 60555-3 1987
- IEC 1000-4-2

These products needed innovation for several reasons:

- to follow the market request evolution;
- to improve the production , parameters stability, to include auto diagnosis facilities to comply in a flexible way with different plant requirements, and finally a feature that is becoming more and more important the integration to a home automation environment;
- intellectual property protection against pirating companies.
- lowering the costs of both the company's products and the mounting costs of the boiler system;

As far as the cost of the old products is concerned, the main points are summarized in the following tables:

Flame modulation	
Material and components	15,000LIT (6.0ECU)
Assembling and testing	5,000LIT (2.5ECU)
Margin	12,000LIT (6.0ECU)
TOTAL	32,000LIT (14,5ECU)

Ignition controller	
Material and components	14,000LIT (7.0ECU)
Assembling and testing	6,000LIT (3.0ECU)
Margin	10,000LIT (5.0ECU)
TOTAL	30,000LIT (15,0ECU)

The remaining cabling, power transformer, front panel, knobs, power switches, lamps and analog meters account for an additional 109,000LIT (55ECU). Thus the cost of the finished control panel is 171,000LIT (86.4 ECU).

We have a target cost for the new integrated controller of 100,000LIT (50.5ECU), without the panel, about a 12% cost reduction.

7 Description of the technical product improvements

It was concluded that a microcontroller was the suitable solution for realising the requested improvements (for an explanation of the reasons see the following chapter)

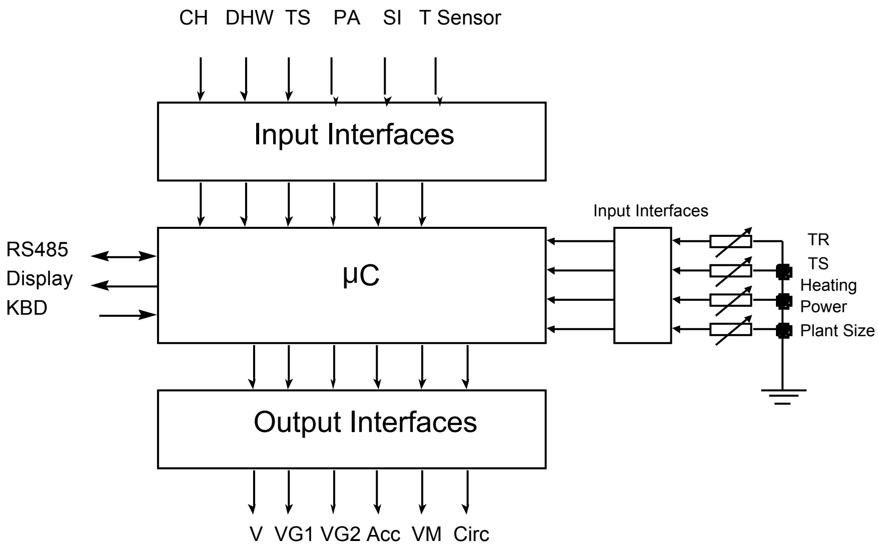


Figure 3

The improved product satisfies all the technical specifications of both the existing products altogether, eliminating as much as possible the cabling. The company envisages a modular product in two boards by dividing the power board and the control board for improved and faster testing and, last but not least, to achieve a better EMC immunity. On the top row in Figure 3, from left to right, are represented the external inputs. both analogue and digital. On the right side are represented the on-board trimmers that preserve the same meaning and enter a signal conditioning block prior to be read by the microcontroller unit.

A PIC 16C74 with 4 K PROM was used for the AE

The microcontroller software operates the flame ignition and modulation procedures, while providing self test and self diagnosis facilities. The controller is continuously checked for any abnormal condition via a set of safeguard devices both hardware and software (watch-dog, signatures, dedicated memory tests).

The outputs are represented on the bottom row in Figure 3. All outputs need an interface for signal conditioning for driving the actuators and preserve the same signification as in the current products. On the left side, the user interface is represented and consists of a RS485 interface for future expandability, a two digit 7 segment display, various led displays and a digital keyboard (KBD) for data input. Moreover, a few dip switches are provided for hardware settings, that are not accessible to the user on the front panel.

The new equipment is physically compatible with the existing Ignition Control and Flame Modulation modules so that it can easily substitute the front panel on the existing systems. Using this approach, it will also be easier for the company to acquire the IMQ certifications of the two boards, permitting the future development of another controller by re-using the power board.

FUSE Demonstrator Document

The new product has very important new features regarding the safety issues , much improved long term stability (mainly for the critical timers that now have crystal oscillator precision for the product life), auto test capabilities, versatility and flexibility for fast and cost effective adapting to new customers requirements or for future upgrades by adding communication capabilities.

The existing ignition control module makes use of an electromechanical chain designed to drive the system in the safe lock out state if abnormal operation of the system is detected. The new component inherits this safety electromechanical chain by the series connection of the power output relay contacts. Every relay is IEC 255 compliant and its coil is continuously tested by means of an analogue signature voltage. The new feature is required to detect the failure of the microcontroller or of the I/O interfaces at start up and during the operation. If an abnormal operation or failure is detected, the module will drive the whole system in lock out safe state, as the electromechanical chain of the current component does.

Safety for this kind of applications is a very important issue, a particular attention being paid during the CE standard certification procedure. For a complete fulfilling of the safety requirements, the safety features of the new component will join the existing product safety measures, leading to redundant safety check.

EMC has been particularly evaluated and taken care of by applying filters, RC snubbers, varistors and by a proper printed circuit board layout. A good ground plane has been provided where applicable. The microcontroller philosophy should also facilitate the parameter variation and the functional logic modifications that could be requested in future by other customers.

At the beginning of this design the major stress was concerning an improved functionality and easier manufacturability. By proper design and component choice were also obtained a significant cost reduction, which was not so evident at the start of the project.

A further benefit is that the number of sensors is usually not so low on conventional designs; even their cost is commonly higher. Finally the burner builder can have a single supplier of the finished goods and does not need an external cabling company.

Obviously the choice of a microcontroller technology enables the First User to easily change and/or expand the application software. This is simply impossible using a conventional analogue implementation as used on the old product.

A strong point of competitiveness requested by the customers is the ability to furnish customized versions of the software. This was clearly impossible with the old product technology.

Further advantages that can be gained using a microcontroller realisation are:

- Increased reliability (thanks to integration and the reduce count of soldering joints)
- Better EMC behaviour (due to the shortening of ground loops because the PCB are smaller and with fewer components)
- Smaller and lighter equipment

8 Choices and rationale for the selected technologies, tools and methodologies

The alternative design solution available for the implementation of the redesigned Ignition Control and Flame Modulation products were evaluated using the following main criteria: adaptability, cost, and the ability of the company to acquire the necessary skills so as to use the new technology in other company products

The main objectives of the new product development were:

- Reduced cost
- Higher integration
- Increased reliability
- Improved flexibility
- Auto diagnosis capability and safety requirements fulfillment

Potential solutions to the company's requirements were:

- more advanced discrete solutions: the products may be redesigned making use of more advanced analog and digital off the shelf ICs. However, this solution does not enable remote programming or provide a significant reduction in the complexity. It might result in a slight cost reduction over the proposed design but does not yield the advantages of flexibility and replicability offered by the microcontroller solution;

- ASICs or Gate Arrays: the medium volume (50,000 units per annum) with at least 30 Mlit. (15 kECU) NRE costs, combined with the target price, makes any of these solutions uneconomical, and limits the flexibility and adaptability of operation. In addition, this solution will represent a high risk approach for the company at this stage also due to the lack of programmability of the technology.

- FPGAs and EPLDs: does not offer the necessary interface circuitry (A/D and D/A converters, 7 segments or LCD drivers) and therefore additional external components are needed increasing the final product cost. This solution also limits the flexibility of the product; moreover the price of these components would have been at least 25% larger than the one of the selected technology

- more advanced technologies were not considered because they are too expensive as compared to the product target cost. However, a MCM or Microsystem represent a very risky jump for a company of this size and experience.

- microprocessors and microcontrollers: these devices clearly meet the flexibility requirements for the enhanced product.

A design based on a microcontroller represents instead the most affordable and profitable technological step forward for a company with this profile and background. Moreover, the improved product is considered to be very competitive on the gas burners market for its price, performance, and reliability, therefore it is important for the product to be easily modifiable with the addition of new features to keep pace with the market evolution. In a microcontroller solution the software can be ported to a microcontroller in the same family featuring more options, thus smoothly upgrading the product to satisfy future market requests.

As far as the microcontroller choice was concerned we investigated the cost-performance and analogue interface facilities of ST6 from SGS Thomson, TEXAS 370 family, Hitachi, and PIC and the last one has been effectively chosen as the best candidate for cost, availability and system configuration.

Microchip PIC family features a RISC technology which assures a higher reliability in the instructions execution. Moreover the fast execution speed gives enough bandwidth to allow the execution of many redundant software checks required by this particular application.

The Microchip development tools include several useful hardware and software systems to help and assist the developer in design and testing process, such as: a PC hosted integrated environment that includes a cross assembler, a simulator, a support for the device programmer, all integrated into a unique environment.

Finally, in the production stage, the whole control software will be written into the masked ROM of the microcontroller. However, the code can be protected from reading even on the OTP device.

The design and assessment methodologies were tailored to the peculiar characteristics of the industrial sector where the company operates.

The simple programmer board PICSTART and the more complex PROMATE2 were extensively used by the First User under the guidance of its subcontractor.

The MPLAB simulation software was also used for simulating the behaviour of the microcontroller. An In Circuit Emulator was not considered as necessary.

In the target equipment, the controller monitors several sensors and operates many actuators whose features (thermal, chemical, hydrostatic, and pneumatic) were hard to be modeled with high level design approach.

Therefore during the test of the new device, the breadboard was interfaced to the real sensors and actuators, identical to those found in a targeted gas burner. This design strategy was able to ensure the assessment of the operation of the microcontroller and its I/O interfaces in real operating conditions, with real input signals, loads, parasitic effects, delays, EMC problems etc., and leaded to the development of a robust and safe firmware for the microcontroller.

9 Expertise and experience in microelectronics of the company and the staff allocated to the project

OSELIN ALBANO d.i. designs gas burners control equipment for the Italian gas burners manufactures. The company has electronic design expertise in the development of products incorporating discrete analog devices, and in the test of “through-hole” and SMD printed circuit boards (PCBs). The company uses low cost semiautomatic test approaches to product functional testing, and does not possess any kind of automatic test equipment.

The company does not have microcontroller design and development expertise, and does not possess any experience in developing integrated design solutions.

10 Workplan and rationale

The main tasks of the application experiment have been the following:

- Project and technology management
  The company planned and controlled the application experiment flow, provided the TTN with monthly progress reports and contributed to the creation of the dissemination material for the application experiment and to organization of all dissemination events throughout the whole application experiment development. The subcontractors participated in defining the training and the timing of various application experiment development phases and provided also monthly reports.

- Training
  The company received basic training for leading an effective project management from the TTN.
  Two company persons received a one week training for designing with microcontrollers. During this training phase the First User acquired the basics of microcontroller technology like: microprocessor architecture, memory banks, interrupts, I/O interfacing, instruction flow, etc. This basic knowledge was needed to test the product and will be valuable also in future products using the same technology.

  The technical subcontractor also organized and provided training sessions for project and technology management and technical on-job training.

- Design specifications
  During this phase the detailed functional, EMC, interface, and testing procedure specifications of the new product have developed in about one month time.

  This phase was very important in order to educate the First User in defining a design work plan and the functional specifications. This way the subsequent design phases had a consistent and well detailed base that assured a fluent design flow avoiding excessive recycling processes.

  The company supplied the system know-how while the technical subcontractor contributed to define the interfaces to the microcontroller and the final evaluation procedures.

- Hardware and software design

  This phase began with developing the I/O signals conditioning for two weeks and assembling a test-bench. Using this test-bench the microcontroller firmware has been developed for both Ignition Control and Flame Modulation functions in the next month and a half by the technical subcontractor. Next two months and a half have been allocated to introduce auto-test and safe if fail behavior and debugging the code. One month and a half at the end of this phase has been devoted to PCB design and fabrication and prototypes testing. During the whole phase a tight interaction between the First User and the technical subcontractor was envisaged and the experience and good work practice of the subcontractor induced effectively even more interaction for the benefit of the design development schedule and the suitability for its industrialization.

- Final evaluation of the prototype

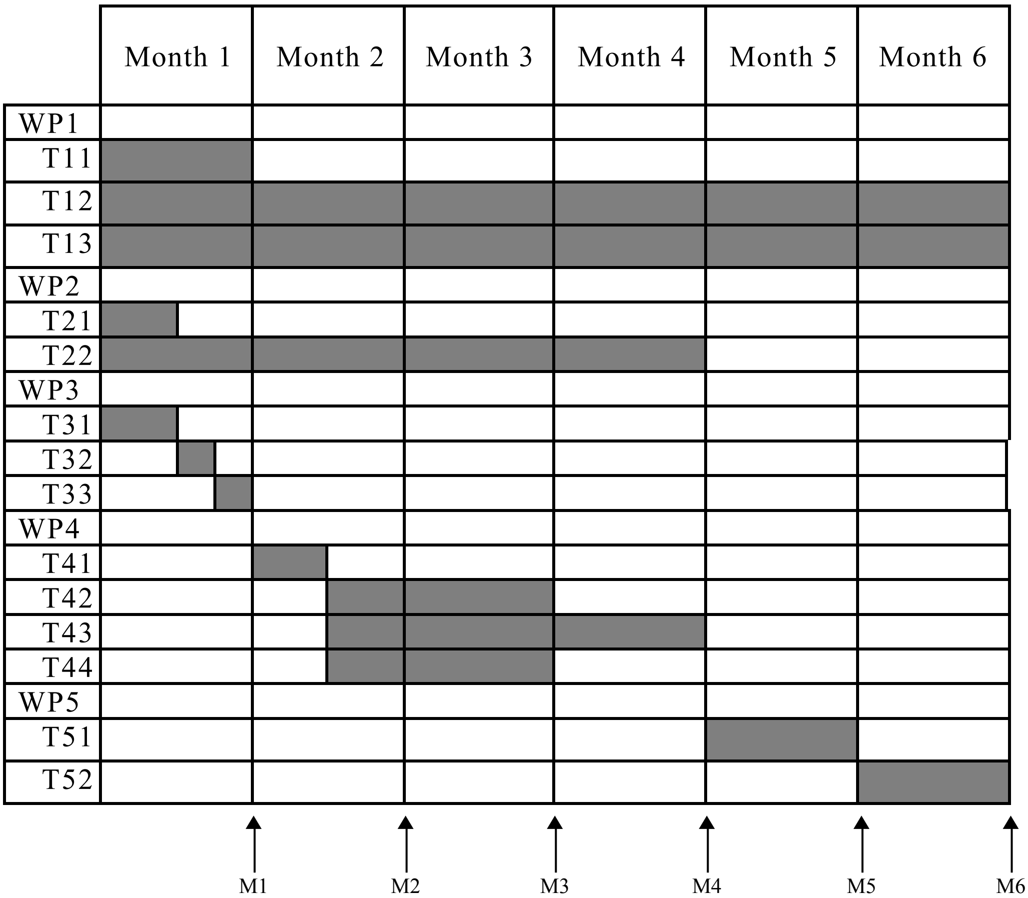
  The objective of the first month of this phase was to assess the real performance of the prototype with emphasis on safe-if-fail conditions. The last month has been dedicated to laboratory testing of conditions for checking the EN298 standard compliance in view of product certification.

As already pointed out in section 6 and 14, the new product was designed slightly different from the solution envisaged in the original AE proposal. The change consisted mainly in separating the two boards no longer based on their functionality in the boiler system (because the new trends of the market), but on the practical reasons detailed in the aforementioned sections.

Another change with respect to the initial proposal affected the auto-diagnose function of the system. It was changed the procedure and the tool from a portable PC running a dedicated test and diagnose program to an embedded self test procedure using the built-in display.

However, thanks to the very good design modularity and experience of the subcontractor, the flexibility needed for this change was easily obtained during the design phase without changing the original work plan neither as workpackages/tasks nor as time frame of the deliverables.

Application Experiment Bar Chart:



Cost and effort for each participant in each WP

	First User		Subcontractor	
	Cost [kECU]	Person/days	Cost [kECU]	Person/days
WP1	2	20		
WP2	1.5	10	6	15
WP3	1.5	10	2	6
WP4	2.5	35	8	35
WP5	3	25	2	10

With respect to the initial AE proposal were changed two main specifications.

The first one concerns the maintenance tools. At the beginning of the design it was thought to employ a notebook PC with an embedded software that should analyze the system failures communicating through a RS 232 serial interface. Then, at a second stage, it was evaluated that a notebook PC could be too expensive for many gas burner installers and it was opted for a dedicated LCD terminal to be produced at much lower cost. At the final stage it was decided to devote the same temperature display as an error display differentiating its function by means of additional LED indicators. By this way even the end user is able to identify common failures and to communicate them to the installer in advance. This enables the installer to bring the appropriate spare parts in the first travel.

The second modified specification regarded the boards system organization. In the first version the functions of Flame Modulation and Ignition Control were split on two independently working boards. Now the system was rearranged on two boards, but which group the power on one board and the signal the other. This is due to the fact that the First User realized that the market now requires the two functions always bounded. By eliminating the function separation requirement it was first considered a single board solution. But the requirements were different for the circuit functional blocks: the high voltage section required 3mm spacing between adjacent traces, while the microcontroller section required good ground planing and higher density component placement. The best solution by far was now the separation on two different boards of the power section and the control section. A side benefit for the First User is also that it’s possible now to certify the two boards separately and the development of a similar product by reusing the already certified power section.

11 Subcontractor information

The company has selected a suitable subcontractor to support the development of this in-house embedded microcontroller design capability. Several possible subcontractors were examined comparing expertise and experience at the end a good trade-off between cost and offered support was negotiated with one of them:

This subcontractor was selected for the following reasons:

- extensive prior experience of developing control products using microcontrollers;
- the ability and agreement in the objective of transferring knowledge via a cooperative development process;
- disposability to periodical checks of its design results against the requirements of the contractor to ensure the full satisfaction at final delivery;
- as local subcontractor the company is able to provide technical support throughout the introduction of the design to manufacturing;
- cost effectiveness.

The subcontractor helped in defining product test procedures after beta-test phase and enabled the understanding where to apply similar technologies in future products and designs. By means of a constant relationship with the subcontractor during the design process the technical knowledge of the First User was improved, not only on the specific product that was designed but also on the general technological culture of the company. The subcontractor was able to advise and refine the design workplan and also advised the acquiring of programming tools and development systems. The developed design included valid indications on the components choices and suppliers identification.

The contract consists of a subcontractor offer to the First User and the subsequent order of the First User. On the subcontractor’s offer are reported the conditions of delivery. In particular it is explicitly provided the transfer of the intellectual property rights from the subcontractor to the First User. In this kind of contract no penalties are explicitly defined in case of delayed or missed delivery, as could be for a hardware supply contract.

The contract explicitly defines the items and the delivery conditions that should be supplied by the subcontractor.

Some further suggestions can be given on the basis of our experience to improve the relationship with the subcontractor:

- Accept the suggestion of the subcontractor for product adds on to increase its commercial value

the First User experienced an imaginative subcontractor who gave them various inputs during all the development phases. These inputs are not commonly given in general, but now the First User is effectively able to request these interactions when needed:

- Provide him with all the necessary information without too many confidentiality barriers

in order to enable the subcontractor to develop the design the FU supplied, since the beginning, every schematic both of the old product boards and the complete burner system. It was also demonstrated a working traditional system applied to a plant simulator;

- Include special regulations and recommendations in the specifications definition

the subcontractor examined the EN298 norm as a project prerequisite, after this phase it was agreed a commonly written technical specification;

- Install a common development framework

special care was taken to install and maintain the same development systems as the subcontractor's in order to achieve the same results by compiling and targeting the developed software.

12 Barriers perceived by the company in the first use of the AE technology

There were several barriers that have prevented the company from adopting a new microelectronics technology to improve its products and compete more favorably in the market place. These barriers included:

Knowledge Barriers

The company knew that there is a growing need to improve its products due to the increased competition in this area from existing and ever emerging companies. The company also realized that continuing with the existing products will limit its ability to grow. In addition, there was an understanding that the required solution lies in microelectronics. However, the company did not have the answer to many fundamental questions including:

- what are the appropriate improvements?
- what are the possible solutions?
- what microelectronics technology is more suitable?
- where can answers be found?

Psychological barriers

Similar to many small companies with low level of expertise in microelectronics, OSELIN ALBANO d.i. faced several psychological barriers. There was a genuine fear of any technology more advanced than discrete components and PCBs and strong perception of high risk. The belief that adopting a new technology is risky, stems from the fact the company had a feeling of technical inadequacy. As a result the company's natural approach to improve its position was to consider other solutions such as better marketing, mechanical and aesthetic improvements, rather than microelectronics.

Technology barriers

The limited knowledge in microelectronics has manifested itself in technology barriers that have contributed to the overall difficulties of introducing a new technology. The company was not able to choose an appropriate microelectronics technology to solve its problems and even when the microcontroller solution was selected there were additional technology barriers that had to be addressed including:

- limited technical management capabilities;
- primitive project management skills;
- lack of expertise in microcontroller hardware and software development.

Financial barriers

Financial barriers tend to be significant for small companies similar to OSELIN ALBANO d.i. with relatively low turnover and limited resources. Any investment in research, development and training can affect the production and sales because resources have to be diverted away of the main business activities. Therefore, there was a strong perception at the company that the necessary technology step can have significant financial implications and represent a high risk. The financial barriers coupled with the limited knowledge of technology costs resulted in the magnification of the psychological barriers.

13 Steps taken to overcome the barriers and arrive at an improved product

The process of overcoming the barriers facing OSELIN ALBANO d.i. in adopting the new technology started following the initial contact with the TTN. During this process the company was provided with training by the TTN on the following topics:

- the available microelectronics technology options and their merits;
- the economic and business implications of adopting the new technology;
- technology and subcontractor selection process.

OSELIN ALBANO d.i. conducted, with the support of the TTN, a detailed feasibility study into the improvement of the Ignition Control and Flame Modulation and other products in the future. This study has resulted in the selection of microcontrollers technology and covered the technical and economic aspects of adopting the technology. The feasibility study was documented in the form of the FUSE proposal for this application experiment.

The initial training, feasibility study and the preparation of the FUSE proposal have allowed the company to address and overcome some of the barriers listed in the previous section, especially the knowledge barriers, and some of the psychological barriers.

Technology management capability was also addressed in the first stage of training from the TTN while best practice in project management and control were acquired during the monitor meeting and design review along the whole AE duration

Thanks to knowledge acquired in technology management, the First User was able to accurately estimate since the early phase the effective costs and payback period of such design.

In the same way, the First User understood that many difficulties he was worried about could be faced with a careful and rigorous work plan, although at the beginning the work plan was mistakenly considered as waste of time. Now it should be able to manage future designs by establishing a correct and meaningful timetable containing the necessary milestones and deliverables.

The most important lacks of technical knowledge (choice of the most suitable component, selection and usage of the proper design tools, design flow with a microcontroller) were covered by the training offered by the subcontractor.

In particular the not conventional approach followed for the training approach was very appreciated by the FU

A formal course structured in lectures was only given at the end of the project, in such a way it acted as a systematic and more theoretically justified review of what has been already learnt during the on job training phase,.

This broke another important psychological barrier toward training since the FU approached it in a very practical way

14 Knowledge and experience acquired

- Through this AE the First User was placed in position to independently evaluate the feasibility and applicability of this technology on similar products or whatever electronic system that can be conceived and more specifically: He is now aware of the repeatability of digital technologies against conventional analog solutions and considers favourably the introduction of the same technology extensively on old analogue designs

- The training course and the on job training and first hand experience, have taught the First User to program and to manage the image files of programmable devices.

- From the analysis of the schematics and the self diagnosis error messages, the First User improved its understanding about the identification of component failures, which now follows a logic approach by eliminating at the beginning tolerances side effects.

- The First User is now able to address EMC issues as a design task and not as a final ad-hoc design fix. They embed the same criteria and methodologies on other designs which have the same kind of problems.

- When the First User examines a new design, they now have a broader range of choices for evaluating the costs of the finished products in relation to the different technologies.

- The First User is now able to better define its requests to subcontractors in order to define the project milestones to be reached and to better describe functional and interfacing specifications;

A very interesting experience was the usage of the PIC development tools

Training was the key issue for breaking the barriers to the usage of the tools

The necessary training included a prior definition of the specifications of the system, together with a functional show of the old product. After this phase, the subcontractor kept a course to the FU's company regarding the main hardware and software concepts and architectures of microprocessors systems. This course included the basics of digital signal and variables representation, memory banks types and functions, microprocessor functionality, instruction execution, I/O and ADC interfaces, interrupts, assembly language programming, compiling and device targeting.

An important part was devoted to an assisted “hands on experience” on the PIC development tools.

The FU is very satisfied with the capability acquired after the course and the on job training since he is now able to modify the value of constant parameters stored in registers, knows how to address them, and has enough skill to write the assembler for simple routines.

He also understands the difference between the various microprocessor (8, 16 bit) as far as the address space is concerned and which memory to use according to the application.

This was much simpler than it was thought at the beginning mainly due to the attitude of our subcontractor who was able to explain things in a very practical way adapting to the first user initial know how.

The main difficulty was to adapt to a new way of thinking in terms of registers content for specifying parameters or checking operation condition. It took a certain effort to link these issues with the analogue electromechanical world which was familiar to the FU

15 Lessons learned

Looking back to our experience during the AE, we believe that some lessons that we learnt are worth mentioning for other companies who want to go through a similar innovation step.

- Six months time is a quite reasonable period for a company of the size and background similar to the one of the FU to carry out a development of this level of complexity
- Working with microcontroller is an expertise that can be acquired by technicians with an analogue background provided that they are assisted by a cooperative subcontractor able to provide them with the proper training.
- When dealing with microcontroller design it is important to think carefully to the signal conditioning part so as to provide the micro with suitable inputs from the external world.
- When safety is a key point, as it is the case, several “safe if fails” features should be provided both at hardware and at software level, ensuring also the data congruence under EMC disturbances.
- The separation of the power and control part should be considered a good policy, in order to increase the reliability, make testing easier and enable a major flexibility to further changes to the product
- We advice companies who want to perform a similar development to provide a complete hardware simulation of the environment where the equipment is expected to operate. In our case it resulted very useful during the debug to be able to simulate all lamps, pressure sensors, thermostats, temperature sensors, electro-valves, relays with real devices in the FU lab
- It is convenient to involve the subcontractor also in the field test process at the premises of potential customers. In this case the subcontractor participated in the test performed on the controller board at the lab of JOANNES Finterm.

16 Resulting product, its industrialization and internal replication

Resulting Product

The product realised has proved to be fully compliant with the specifications and well crafted for the market targeted by the First User.

There are however differences from the initial specification.

The end user maintenance phase was considerably simplified and made at the same time cheaper. The initial project made use of a portable PC running a dedicated testing application for devices system testing. This tool was considered too expensive and not so easy to employ by some installers. Moreover the end user had no indication of what could have been occurred in the burner after a lock-out condition. These characteristics could negatively effect on the capacity of the new product to enter high-end markets. At this point the error handling was rethought and in the final version an embedded error detection was provided. With this feature the system eschews dedicated software procedures that actively monitor the system hardware and variables range and consistency. When an error condition occurs, a unique numeric code is displayed which identify a system or board failure with as much precision as possible.

By means of microcontroller technology it was possible to remove many final tests on the product. For example once assured that the oscillator is working, surely all the timings of the functional logic are correct. Moreover, the above mentioned display helps to identify eventual board failures. As a final consequence product repairing can be much shorter due to the failed block identification by the built-in test.

Another main difference from the initial planning is concerning the partitioning of the system boards.

Once the board partitioning reflected the old product by using a Flame Modulation board and an Ignition Control board to enable the direct in circuit substitution of old boards.

After the First User better evaluated the market, it decided to group the two functions to achieve lower costs and to better serve its customer needs. At this point, a single board could be a viable solution, but by better considering the specifications for voltage isolation and EMC compliance as well as the certification costs and the subsystem reusability it became clear that a two boards approach was the obvious solution. Following these criteria the new splicing provides a control and a power board. The power board was optimized for high voltage design rules while the control board was optimized for EMC compliance and high density component placement. Another added benefit for the First User is separate board homologation and the possibility to produce and test every board independently and reuse the power board on future products.

The First User planned to handle the production in the following way:

- the power board will be assembled by third parties both for SMD technology and traditional one. The needed materials will be procured by the First User;
- the control board will be assembled by third parties only with respect to SMD technology, but will be finished internally by the First User. In particular this finishing includes the application of the programmed microcontroller which is correctly considered a strategic device;
- both boards will be tested by the First User in two phases. The first phase tests the power board on an internally built and conceived ATE. The second phase tests the full two boards system. The first phase should last about 15 seconds at maximum, while the second test can be executed at different levels. The fastest one can last no less than 2 minutes, as at least a full ignition cycle must be exercised. On the other side for AQL testing a plant emulator has been built which includes a cycles and an hour counter. This emulator is used for accelerated life testing which envisages many stress cycles.

Industrialisation

In order to industrialise the product the following steps will be completed:

- PCB final version definition. The experimental PCB needs some adjustments in order to accommodate the finally chosen components. The expected cost for this operation is in the order of 800ECU, including film developing;

- testing machines making. To test the two boards as above mentioned the First User plans to assembly two PC hosted ATEs with printed logging report facility. The expected cost is 7600ECU;
- IMQ certification. IMQ represents the Italian competent certification body and the expected cost is in the order of 8 kECU;
- plastic molding engineering and tooling. This cost is not properly applied to the electronic product, but is anyway to be considered for the product boxing and customization. It is evaluated in the range of 20 kECU.

The reported final costs are matching the initial estimates because the final dimension of the PCB reflects the dimension of the front panel which was previously evaluated as the worst case condition.

Maintaining the access to the subcontractor's facilities means for the First User the ability to obtain revised and new versions of the application software which are fundamental for further applications development and the First User took already the first steps to extend the collaboration.

The acquired skills are maintained by the production and test process.

Internal Replication

Microprocessor technology will soon be used to develop a new burner control for equipment using fuel oil instead of gas.

Another application that the F.U has under study is a remotely controlled burner with an LCD display on the remote controller board. The First User intends also to apply the new acquired technology to enhance the performances of other products in the anti-intrusion and anti-burglary sectors where he has currently a very limited market.

The First User already plans to improve the new product to make it suitable for use in the high-end gas boilers market by introducing a remote control facility. This product is expected in the second half of 1999 and will cost 20% more but have a higher margin. Sales are expected to limit at about 2500 pcs/year.

Another derivative of the new product is the ignition control module using the microcontroller technology. This one is expected for the second half of year 2000, limited to some 20,000 pcs./year in the next 2 years. The selling price and the margin will be similar to those of the current Ignition Control module but with improved performance/price ratio.

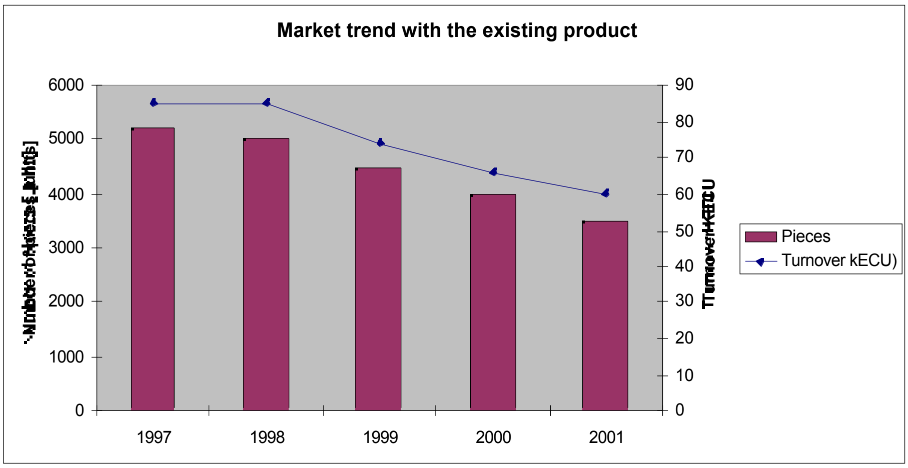
An important new application of the new technology is the oil burner controller that the First User hopes to extend to 5% of the market increasing from about 2500 pcs./month in 1999 up to 10,000 pcs/month in 2001.

Other applications of the new technology include the radio remote controls encoder and auto-learning for programming, although with a marginal impact on the First User business.

17 Economic impact and improvement in competitive position

The sales last year (1998) and the projection for the next three of the Ignition Control and Flame Modulation together are reported in the next figure

The projections of our next period sales for this product indicate a clear decline, although the



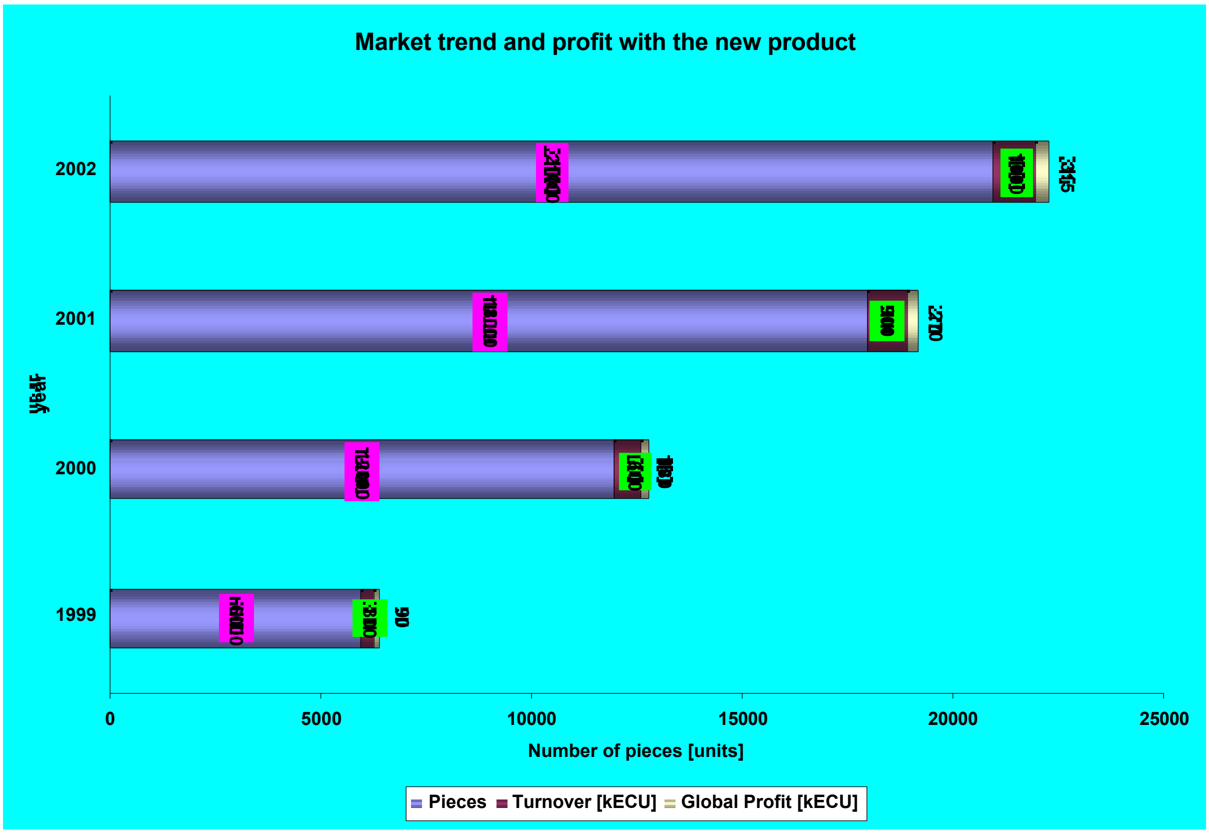
total market for gas burners is expected to show a growth in general. The reasons for this are:

- customers become more and more sophisticated and demand extra features which cannot be delivered by the current analogue discrete technology.
- additional competitors keep entering the market taking advantage of the low level technology of the existing systems and the relatively unprotected IP.
- the market trends show a tendency towards the improvement of the functionality of the products that cannot delay too much the introduction of more advanced technologies in the field. In fact, at a recent exhibition that the First User attended were presented similar products using digital technology as in this application experiment. This is considered an important sign that the market is now mature to receive such products, which was not the case a few years earlier, thus the First User's intuition was right.
- With the new product, the First User aims mainly to consolidate its present position and to expand as provider for as many as possible gas burner manufacturers while entering the market of providers.

The economic impact of the new technology can be seen under multiple aspects due to the modular construction and the versatility of the new product. It will represent a highly competitive product for the gas burners market in that it will offer the two functions (ignition control and flame modulation) performed by a single, easy to install and maintain module.

The company's main market policy will be centered instead on the exploitation of the new product as a two-in-one module. Moreover, replacing the old products with the new one represents for the company a great simplification in terms of production and certification procedures together with the reduction of the overall costs. The major strength of the new product comes when it replaces both current products at once. According to the company's Italian market information, there are at least two big low cost gas burners manufacturers (LAMBORGHINI and OCEAN) that are highly interested in an integrated, high performance and low cost solution for the gas burner control. These manufacturers use now a low cost solution that is incompatible with the market standard.

The turnover and profit estimations for the new product is presented in the following graph



Another important market share that the company can enter with the new product is that of spare parts. The spare parts are now under the control of the big manufacturers that deliver the spare parts three times the cost they pay the modules to their providers. The new product flexibility and convenient cost, as well as the much improved performance and reliability will place the company in a privileged position. The company is part of a consortium that actively seeks to enter as many markets as possible, including that of spare parts.

The projected turnover allows the company a very fast payback period. In fact, the 34.7 kECU, that are about 68.7MLIT, need approximately 4500 units of the new product to be sold to recover the investment. This assures recovery of the investment during the first year of sales. This short time is very positive because the company's market sector is in continuous movement and the market life of a product is relatively short. Continuous innovation being required.

As far as the return of investment (ROI) is concerned the cycle time of the investment should be considered of 4 years since market requests change very fast in this field..

The total cumulated profit in 4 years should enable our company a ROI of about 17 times the initial FUSE investment.

This computation is obviously non realistic because. the company will be forced to increase its size, design, testing and sales forces in order to satisfy the highly increased demand.

It is certainly difficult to make at this point a precise estimate of the investment the company would have to sustain to this purpose but we guess that this will be as large as five times the FUSE budget and that reduces the expected ROI to a more realistic 4 times. The global sustained investment can be considerably lowered due to the fact that the system is composed of a single assembly, every connector to the field is polarized and with a significantly reduced number of wires compared to the previous solution. The product is boxed into a plastic moulding that protects it from user tampering.

The expected production costs of the new product are the following:

New product	
Material and components	50,000LIT (25.2ECU)
Assembling and testing	15,000LIT (10.1ECU)
Margin	35,000LIT (20.2ECU)
TOTAL	100,000LIT (50.5ECU)

Testing costs are also reduced, as testing becomes much easier since a lot of self-test functions have been implemented onto the same board. The display shows a unique error or failure condition by identifying a component or subsystem failure. Much lower scrap during testing and even in that case a much shorter time to repair a failed board is expected.

The burner builder should also benefit from the reduced number of cabling wires, the time for connecting the plant devices to the new product is shorter. In this way the product reliability and maintainability is further improved.

- the sales volume for both old products altogether, the Ignition Control and Flame Modulation. The constant decline was one of the alarm signals for the First User that it is loosing market share in favor of second suppliers, that first brought a lowering of the selling price, then a reduction of orders volume. The projection for the coming three years shows the same worsening;

- for the new product, that is expected to hit the market starting with the first quarter of the coming year, it is foreseen a better market request due to its much improved functionality and economic attractiveness. For the following years is forecast a constant growth of the request that the First User is already prepared to face. Although the unitary turnover is not higher than for the old products, the overall turnover from the selling of the new product will be much higher because of the higher volume of sells.

For the new product there are some marketing considerations to be mentioned.

First of all the new product offers much improved functional characteristics and ease of maintenance as it was explained in the dedicated section. Moreover, with the installation of the new product the gas boilers makers will be able to save important production costs from the ease of assembling. In fact, the new product requires lower cabling and features easy to plug and fool proof connectors. This is considered by the First User as a key feature in attracting new customers.

At the fair of Milan this year the First User noticed the market tendency to shift to electronic controls for the gas boilers from old electromechanical or pneumatic. The electronics in this field, even the microcontroller technology, are no news anymore, the market is now prepared to accept it.

The new product is easy customizable for different types of gas boilers. Even more, the new product can be proposed for new lines of gas boilers that can be designed to fit the new product instead of the other way around, thus contributing with some elements of standardization in the field. The new product should be preferred because of its easy mounting and maintenance, as stated before.

The introduction of the new product on the market should not interfere with the sales of the existing product since the boiler lines that mount them are different. Thus, all the income resulted from the marketing of the new product constitutes additional benefit for the First User. Without the introduction of the new product all this would be lost.

Besides the prototyping costs that are the object of this application experiment the First User will support additional costs for the industrialization of the new product. The certification costs (Italian IMQ) are in the range of 15MLIT requiring additional laboratory tests of about 2 months (failure analysis, climatic tests, lifetime, etc.) that amount to 10MLIT. The new instruments and benches as well as industrialization-wise design of the PCBs add a supplementary 40MLIT to the expenses.

The marketing of the new product is made by a consortium the First User is part of and which promotes the new product on as many markets as possible charging 2% per sold unit.

The new product will be sold for 100 KLIT hoping to increase the domestic market share of the First User to about 10% of the total at the end of the third year, The cost is higher than initially envisaged because it was decided to design a top level product instead of just mere replacements for the old products. The provision of recovering the higher cost for the customers is that they will spare very much on the related production costs with respect to the old product, as was explained earlier in this section.

Taking into account the extra expenses to be supported by the FU, the ROI will be reduced to 400% over 4 years.

To ensure the marketing success of the new product the First User is already in contact with three potentially new customers that have 3%, 5%, and, respectively, 4% of the gas boiler market share in Italy

18 Target audience for dissemination

OSELIN ALBANO d.i. operates in a highly fragmented market consisting of many different size suppliers providing bespoke systems to meet individual contracts assigned by local commercial and industrial facilities managers. In Italy the company's market assessment indicates that none of its competitors currently use microcontroller products to meet customer requirements.

This application experiment will therefore provide a unique experience of special interest to such companies through Europe, and will demonstrate how the assimilation of a microcontroller design capability can be undertaken with low risk and result in a significant commercial benefit to their business. It is envisaged that a significant penetration of this technology into a range of gas burner control products and meeting European norms and legislative requirements will result in important commercial benefits to many European companies.

This application experiment will also be of interest to small companies currently capable of developing discrete circuit boards, but that are unable to commit themselves to microcontroller technology, as was the case with OSELIN ALBANO d.i., because they are unable to devise appropriate knowledge development strategies without jeopardizing existing customer service relationships.

The dissemination of the development of subcontractor relationships and formal contracts that results in knowledge transfer from the subcontractor into the company will be of special interest to the small company audience.

In general the results of this application experiment will be of interest to companies operating in a wide range of sectors including:

- EN (Energy production and distribution, gas and water supply) Prodcom Code 2921

IP (Industrial process control) Prodcom Code 3330