

FUSE demonstrator document
FUSE Application Experiment EPC1 418

Monitoring TTN: IAM F&E GmbH, Braunschweig, Germany

**Prototype of a flame detector employing MCM technology
for the first time**

Abstract

MINIMAX designs, manufactures and supplies complete fire protection systems. The product spectrum covers the complete range of fire detection, fire fighting and fire protection. Extinguishing systems currently makes up more than 90% of MINIMAX's activities. Within the project, the company MINIMAX manufactured a flame detector employing multi-chip-module (MCM) technology for the first time. The MCM-technology allows the design of an infrared multi-spectral sensor/signal unit with 4 integrated infrared (IR) sensors, optical IR-filters and signal pre-processing. The flame detector can be used not only for fire detection but also for the immediate start of extinguishing systems. The present technology using single sensors and SMD technology on PCBs is to be replaced by an MCM module with unhoused sensors and bare dice on hybrids.

This advanced integration technology results in space and cost reduction and higher reliability due to improved EMC (electromagnetic compatibility) behaviour. During the application experiment, the technology of applying bare dice (hybrid and MCM technology) is transferred from an experienced industrially oriented institute to the First User. This gain of know-how and experience will enable the First User to access and use this new technology in their future product development. The Application Experiment took 12 months. The development costs ran to 104 KECU. The payback period including the industrialisation will be about 3 years and the lifetime of the product is expected to be about six years. This will enable an ROI of about 250 %.

The Application experiment is of interest for companies working in the area of security systems or in the area of advanced sensor systems.

1. Company name and address

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2. Company size

The total number of employees in Germany is 2678, with 27 involved in the electronic development. The turnover of the company is about 270 MECU.

3. Company business description

MINIMAX belongs to the small circle of international fire protection companies able to supply complete fire protection systems. The activities of Minimax GmbH are subdivided into the sectors „Fixed Fire Protection“, „Mobile Fire Protection“ and „Foreign Group Companies“.

The Minimax programme includes the complete range of products required for fire-fighting and fire protection .

The business of Minimax GmbH is fire protection with all associated fields, such as consultation, construction, engineering, delivery, service, distribution, and maintenance of complete fire protection systems. Minimax is one of the leading company in extinguishing techniques. More than 90 % of the business is concentrated in the field of extinguishing systems. Minimax is also successful in customer-specific applications such as spark extinguishing systems, automatic fire extinguishing systems for paint spraying plants, fire protection on ships and offshore units and fire prevention for computer centres.

4. Company markets and competitive position at the start of the AE

There is no statistics available of the world market for infrared flame detectors. However there are 15 different certified infrared flame detectors available with German standards (nearly the same as EN 54 for Europe):

- Only 6 companies offer these products.
- 5 of the 15 different detector types are fabricated by Minimax
- 4 of the 6 companies are manufacturer, the other 2 buy from other producer.
- All 6 companies operate world wide and they belong to the main group of suppliers in the European market.

At the moment there is one supplier/producer from the major US market certified in Germany. It has a high level in technology, high quality and a strong, powerful position in the market.

Ranges of application are public houses, industrial plants or office buildings.

The customers of the product are as well private people as companies that want to secure their buildings against fire. The market is not only cost driven, because a very decisive argument are the possibilities for false alarms, that might result in very high costs due to the damages done e.g. by sprinkler systems.

5.-6. Product to be improved and its industrial sector, product improvements

Flame detectors are one type of fire detector. They respond to electromagnetic radiation from a flame. Flame detectors are commonly used for fast, efficient fire-fighting in places where flames can be expected to spread at great speed and where fire can develop abruptly. Some typical areas of application are "high risk - high value" ones, e.g. in gas collection facilities, chemical and petrochemical plants, pipeline compressor stations, refineries, storage tanks and thermal stations. To control protective devices and extinction systems, it is therefore important to have reliable fire detection systems, particularly with optical flame detectors and without false alarms.

Usually, IR flame detectors can detect one or two different wavelengths from the electromagnetic radiation of a flame. Therefore, other radiation sources can produce false alarms. This problem can be solved by using sensor arrays and advanced signal processing.

The technology for the existing flame detector is based on discrete IR sensors in TO housings and SMT/PCB. The new flame detector is based on a highly integrated multi-chip sensor module that measures four different IR wavelengths. In order to achieve reliable flame detection that is virtually free from false alarms, the electromagnetic radiation emitted by a flame source and the background radiation therefore need to be continually analysed in various wavelength ranges. The design and the functional principle are shown in Fig.1.

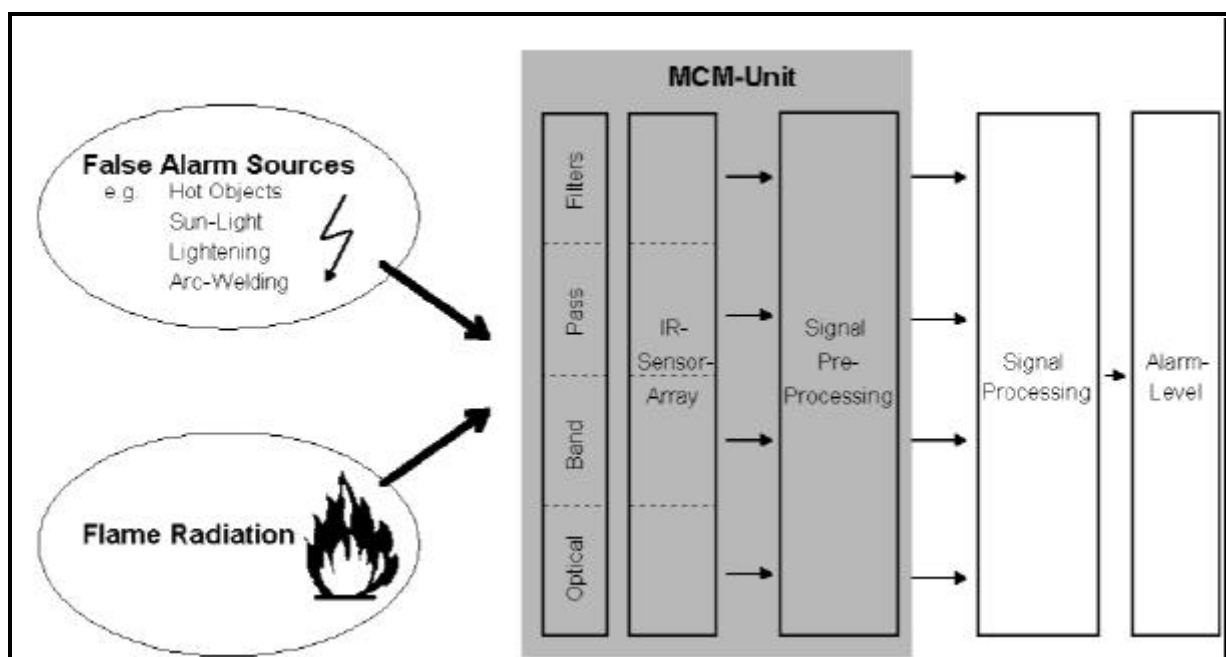


Fig. 1 Design and functional principle of a flame detector with MCM sensor unit

The emission monitor selects three IR wavelengths through high-transmission IR bandpass filters positioned above the heat-absorbing oxinitride membrane of the IR thermopiles. The high-quality IR bandpass filters have pre-defined transmission characteristics with regard to the centre wavelength and half-band width. The fourth channel detects IR radiation below 1000 nm with a commercial PIN diode that already provides a suitable filter.

The chosen sensor thermopiles consist of 80 BiSb-NiCr thermocouples with an IR-absorbing interference layer of 0.26 mm². The signal generated by the thermopiles - typically in the range of a few mV - is amplified by unhoused chopper- stabilised operational amplifiers. The signals from the MCM unit are analogue voltages close to 1 volt. The temperatures of the substrate and of the cold thermopile frames are also monitored. False alarms can be filtered out through advanced signal processing on a separate board within the industrial housing of the flame detector. Should the measured and analysed signals match a pre-defined fire condition, the device sends an alarm level or an alarm message to the central control system to trigger further action. Besides the Application Experiment, the software development took place. The necessary effort to define realistic fire conditions and to use these as basis to program the necessary software has been more difficult than expected, but these problems could be solved due to the great experience of MINIMAX in the area of fire protection and detection systems.

The following figure shows the MCM that is now used for flame detection. The MCM is complete analogue and fits into a 24 pin DIL package. The subcontractor for devices delivers devices tested according to the specification. Prior to the bonding of the sensors, these are tested too.

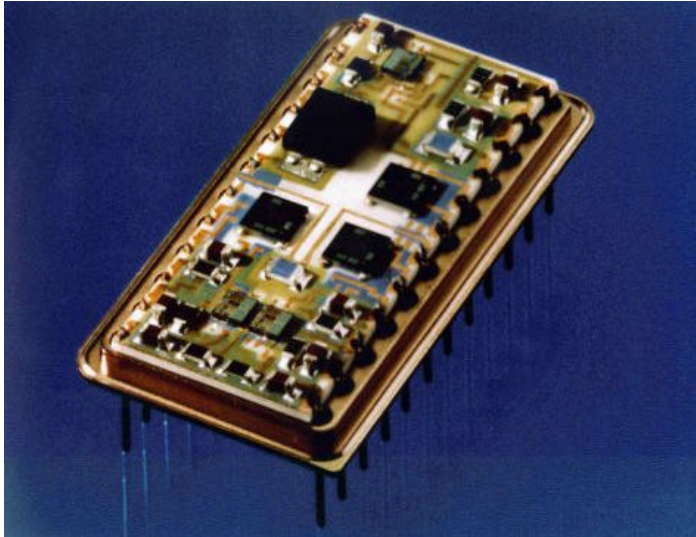


Fig. 2 MCM flame detector with three optical sensors

7. Choices and rationale for the selected technologies and methodologies

Demands

The technological level of the existing detector does not allow a cost-effective design of a sensor module with more than 2 sensors and an identical field of view for each sensor. With the demand of an identical field of view there is no alternative to the MCM technology because the arrangement of conventional devices permits only different views of the sensors and so all disadvantages of the existing product (false detection). E.g. with a standard SMT technology, a miniaturisation as with the MCM technology would not have been possible, so this distances between the sensors would have higher which results in bigger differences of the views of the sensors.

Through successful employment of MCM technology we are able to improve our products in the following ways:

- higher degree of component integration: factor of 4
- improved quality and reliability, minimisation of rework
- high sensitivity: ≥ 200 V/W
- cost reduction in manufacturing (about 20%)

The design of the MCM unit was determined by the demand for high sensitivity with a 90° angle of view for each IR sensor. As the power supply is provided by the central control system, the current consumption of the detector was restricted to below 1 mA. Operation in an industrial environment demanded that it should be sufficiently robust to withstand mechanical stress and electromagnetic radiation. Finally, the MCM unit had to be reasonably cost-effective.

Based on the knowledge gained about alternative MCM technologies, we then conducted a cost-benefit analysis of different packaging technologies and found that thick-film technology was the most suitable to fulfil the requirements. A basic electrical layout was prepared to estimate the space consumption of the elements. The designed integration density could be achieved with two conduction layers. The thermopile sensors and the amplifiers are bare dice, covering an area of about 27% of the available substrate surface.

Thus the unit can be classified as a multi-chip sensor module (MCSM).

Care was taken to optimise the routing between the sensors and the amplifiers. The distance between tracks with the original sensor output and the amplified sensor signal were maximised to reduce cross-talk.

The amplification of the thermopile signals was optimised for the specific demands defined by the flame detection. For better control, the characteristics of the amplifiers can be influenced from outside. The layout of the MCM unit, with the indicated devices, shows the population density on the Al₂O₃ substrate. The substrate had an area of about 15 mm x 28 mm, and was processed in a 4" x 4" panel. The filter carrier was mounted at the centre between the sensors, after the wire bonding and the testing was done.

The passivation print was used to passivate the conduction layers and cross-overs, as well as to provide for sensor mounting studs. These studs provide pressure compensation in the cavity below the membrane of the thermopile sensors.

A filter carrier was designed, carrying the filters to the sensor surface at a defined distance. The filter carrier was mounted at the centre between the IR sensors. The manner in which the IR bandpass filters were mounted above the thermopile sensors reduced cross-sensitivity caused by multiple reflections inside the package and allowed for small filter sizes. The size of the IR bandpass filters has a major impact on the final price of the whole MCM. The MCM was mounted on a platform plug-in package of the dual in-line type and may be electrically contacted to the pins by wire bonding or electrically conductive adhesive. A nickel cap with integrated CaF₂ daylight filter was laser-welded to the package base, ensuring a stable dry atmosphere within the hermetically sealed metal housing. A special filler gas was chosen to improve the sensitivity even further. This type of package permits operation under extreme environmental conditions, with surrounding temperatures ranging from -40°C to +80°C.

Another economic argument for MCM technology is the cost reduction by using of unhoused sensors. Conventional sensors are much more expensive.

8. Expertise and experience in microelectronics of the company

Minimax is one of the three marked leaders in Germany.

Flame detectors are one type of fire detector. They respond to electromagnetic radiation from a flame. Flame detectors are commonly used for fast, efficient fire-fighting in places where flames can be expected to spread at great speed and where fire can develop abruptly. The application area of the flame detector covers all industrial sectors where fire protection is necessary e.g.

Industry sector: EQ (Machinery, electrical and optical equipment)
CB (Construction and building)
IP (Industrial process control systems)

Among technologies for construction, development and production of extinguishing systems, the following techniques available for producing the electronic components of fire detection systems:

- Design of PCB boards in through hole and SMD technology with standard components and microcontrollers
- automatic placement of SMD components onto printed circuit boards
- reflow soldering
- visual inspection with video coupled microscope
- automatic testing with a Marconi test device

- semi-automatic testing with a Bevercup test device
- computer-controlled measurement and adjustment of special fire detection sensors and fire alarm panel components.

The staff involved were specialists for measurement technology and sensor application, test measurements and prototype production.

Before the start of the AE had MINIMAX no experience in technologies like multi-chip-modules.

9. Work plan and rationale

In correspondence to the application experiment work plan, the following tasks were carried out:

Technical management and training

The First User Minimax is in charge of technical management and takes the necessary decisions in all stages of the project based on the know-how transfer provided in the application experiment. The know-how transfer and the training is realised by active co-operation of the First User with the subcontractor throughout the full cycle of design, manufacturing and testing of the MCM for the prototype flame detector. Further training are also complemented also by participation in MCM- and microsystem training classes organised by the subcontractor and by the TTN.

Specification (1 month)

Choice of suppliers, technical specifications and availability of

- unboxed sensors, bare dice (Minimax)
- hybrid substrates, adhesives, caps (Subconrator)
- Electrical testing of (Minimax + Subcontractor)
 - unboxed sensors
 - bare dice/amplifier

Design (4 month)

- Design and layout: MCM + flame detector (Minimax + Subcontractor)
 - design of MCM/electronic wiring diagram
 - layout of the hybrid substrate
 - design of flame detector/electronic wiring diagram, considering
 - the new MCM sensor unit
 - layout of PCB/flame detector for MCM unit
- Packaging concept (Minimax + Subcontractor)
 - size of substrate, cap, filter window
 - single/double-sided substrate
 - hybrid with pins or SMD
 - arrangement of active and passive components: unboxed dice under cap, housed components surface mounted on hybrid
 - mounting/bonding processes: die attach, wire bonding
 - housing: joining of cap, integration of filter window

Evaluation (9 month)

- Fabrication of the MCM (Subcontractor)
 - fabrication of hybrid substrate
 - laser cutting of caps
 - adhesive bonding of filter window in cap
 - placing and soldering of SMD components

- die bonding/die attach
- wire bonding
- adhesive bonding of cap
- Fabrication of the prototype flame detector: (Minimax)
 - PCB board fabrication including MCM interface
 - SMD technology: place, solder, test
- Electrical characterisation: (Minimax)
 - control of technical data from specification
- Package characterisation (Subcontractor)
 - hermeticity/permeation of He/Ar
 - moisture permeation
 - interface characterisation: cross section of cap bond
- Integration in flame detector and test (Minimax)
 - testing interface MCM/board
 - testing according to standards: CEN, EN 54 part 9, prEN 54 part 10
- Dissemination inside the company (Minimax)
 - future product development
- Dissemination outside the company (Minimax)
 - seminars/joint workshops co-ordinated by
 - publication in professional journal
 - introduction in international standards
- Documentation (Minimax)
 - technical report for technology transfer

The overall distribution of the work is shown in the following table.

Task	Effort (person days)	
	MINIMAX	Subcontractor
Management	35	20
Training	25	25
Specification	10	25
Design & Test	80	80
Overall effort	150	150

Delays:

Although the hardware development of the project could be done according to the schedule and the expected manpower, the delivery times of the filter were a little bit longer than expected, because at the beginning they did not exactly fulfil the specification. So the project had a delay of about six weeks.

10. Subcontractor information

The subcontractor should offer the following capabilities:

- packaging: mounting, bonding, housing.
- qualification of processes, components and packages
- testing according to standards

- process development, including automation
- process evaluation by modelling and monitoring
- laboratory-scale and prototype series production
- compact courses, workshops and seminars, also in-house

Contractual safeguards

The success of an MCM development project depends to a large extent on the precise definition of the obligations and responsibilities of the individual project partners. The party responsible for redesign – and therefore the associated costs – in case of problems must be clearly defined. Without this definition, a project such as this can easily turn into a bottomless pit. To avoid delays in the project, a contract penalty could be agreed for late delivery. Even if it proves difficult to come to a contractual agreement regarding this issue, the effort will pay off since it will reduce the risk of delays and additional costs. It should also be understood that all resulting designs would become the exclusive property of the FU. This is one of the prerequisites for handing the design over to another design partner if desired.

In our experience, the contract definition is of greatest importance. Support from the TTN in advising the FU would be desirable in this activity.

11. Barriers perceived by the company in the first use of the AE technology

Knowledge barriers

Beside the knowledge that the flame detector needs to be improved, Minimax did not know how to realise the new product. The company was not able to choose the appropriate assembly technology, as the electronic packaging know-how ended at the fabrication of PCBs. It was clear that a solution based on SMT/PCB was not the right choice. Even the manner and degree of functional product improvement was a matter of discussion. Given the electronic system functions, very complex circuits would have been mastered on the software/programming side. All the wishes expressed by the electronic development groups and the requested small package outline generated a kind of psychological barrier.

Psychological barriers

The motivation to realise a new product based on a digital and analogue flame detector unit, multiple sensors combined with high integration and optical restrictions frightened Minimax. We saw that too many specific technology steps would have to be taken. Also the handling of bare dice was feared. The risk to fail in product development was present but could not even be estimated, due to the lack of the technological knowledge.

Technology barriers

The technology required was not available in-house. The supply of bare dice, the delivery form, testability etc. were unknown. We did not know whether the planned product volume per year would be high enough to motivate suppliers to deliver bare dice.

Financial barriers

The financial barrier could not be estimated completely. The cost/benefit analysis, although it included many unknown points, indicated, that the prize for a significantly improved flame detector unit could be relatively high.

12. Steps taken to overcome barriers and arrive at an improved product

The first step was the discussion and the choice of optimum and cost-effective MCM technologies.

To overcome **technology barriers** in the specification and the design workpackage, MINIMAX and the subcontractor analysed the possibilities and problems of the supply of bare dice, especially of bare IR sensor dice.

To ensure the **industrialisation** of the developed prototype MCM flame detector, an external hybrid manufacturer was employed in the project from early on. In this way, the MCM assembly did not become too complicated for production. The hybrid manufacturer participated in the learning curve, so as to be able to produce the developed MCM flame detectors after the application experiment.

13. Knowledge and experience acquired

The company did not have any managerial or technical expertise in the application of unboxed sensors and operational amplifiers and did not know about the design and assembly of multi-chip-modules. Therefore, the subcontractor provided a basic understanding of microjoining technology and related materials properties, as an MCM unit is an assembly of different materials in a tight space. The tolerance of the MCM to environmental stresses (temperature, moisture, corrosive gases, mechanical load, ...) determines the reliability of the unit. After the project Minimax is able to handle the MCM-technology, the selection of unboxed sensors and operational amplifiers. The expense to get all this experience was about 2 person month. MINIMAX has learned about a wide range of new technologies, materials properties, product design processes and project controlling. The knowledge acquired will enable Minimax to run similar projects in the future with less involvement from subcontractors only the design and fabrication phase.

14. Lessons learned

Accompanying to the experiment terms, the subcontractor prepared the necessary technological background by lecturing about the next technological step. During the AE, MINIMAX learned, that the following topics are of great importance for the success of such a MCM development:

Lessons in the area of	Important topics
General topics about Multi-chip Modules:	<ul style="list-style-type: none"> • advantages of MCM • classification: MCM-L, MCM-C, MCM-D • MCM-L • MCM-C
Design and layout of hybrid/MCM-C circuits:	<ul style="list-style-type: none"> • design and process flow • data exchange • checklist • preparing an assembly concept • component investigation • placing of components/pads • design rule check • panel assembly • documentation
Layout rules for thick-film hybrids and multi-chip modules:	<ul style="list-style-type: none"> • housing • basic informations • track design • vias, routing • resistor design • wire bonding demands on layout

	<ul style="list-style-type: none"> • testpoints • checklist
Quality in packaging:	<ul style="list-style-type: none"> • Principles of electronic packaging • Standard passive components and multilayer ceramic carriers • Microjoining techniques • Active component packaging • Active component • Discussion and visit of laboratory facilities • Physical test methods • Macroscopic and microscopic failure modes • Product reliability and accelerated reliability testing • Failures in adhesive and wire bonds • Package hermeticity and reliability
Quality and reliability of MCM-C:	<ul style="list-style-type: none"> • quality criteria of thick films • wettability • alloying resistance • bonding strength • bondability • accelerated ageing

These lessons were learnt mainly during many personal discussions with the subcontractor and training in its bonding laboratory, whilst conducting the tasks of the experiment. The specific requirements of bare semiconductor assembly imply demands on the supply of devices. The lessons learned are:

- check the supply of tested devices (e.g. the sensors), or be aware of additional costs, because many companies deliver only tested devices if they are already housed.
- ask for a guaranteed supply for the next 5 years to avoid costly re-designs of the MCM, if the dies will not be supplied any more.
- ask for a storability of devices with guaranteed bondability, because this might influence the selection of parts
- find a second source for devices with same I/O location to further decrease the possibility of redesigns

In the evaluation workpackage a redesign step and additional field tests were necessary to overcome the problems of the relatively low sensitivity. A special test set-up for characterisation and functional testing of the MCM IR sensor array was realised.

15. Resulting product, its industrialisation and internal replication

Industrialisation

The manufacturability has been proved by the MCM prototypes. For the industrialisation, the substrate must be redesigned to facilitate substrate bonding and increase the number of MCM substrates on the 4"x4" aluminium (Al_2O_3) substrate. As the electrical values of the SMD components in the amplification circuits are determined, it may become possible to print and laser trim resistors which will allow further increase in the density on the substrate. The product also demands a structured metal cap to facilitate daylight filter mounting. This cap was not realised during the application experiment, due to the high cost for a punching/forming tool and the delivery time. Series production will not be affected much by this cost.

The introduction of the new multi-spectral IR flame detector into the market is planned for the end of 1998. The following tasks must be carried out to obtain a tested and certified

product for the fire protection marked according to the standards CEN, EN 54 part 9, prEN 54 part 10:

- Completion of field test measurements in the fire laboratory; measurement and signal analysis of different IR wavelengths for different flames and false alarm sources
- Software development for signal processing to filter out false alarms
- VdS certification procedure

This long procedure is typical for fire protection products and is necessary for a high safety and reliability standard.

The new MCM sensors will be fabricated by a subcontractor, who has to deliver tested parts according to the requirements of MINIMAX. These sensors will be used for the fabrication of the overall system, which will be done by MINIMAX.

Internal replication:

MINIMAX gained capabilities as regards the know-how for product innovation. The transferred know-how will be used for evaluation of the present technology for sensor application in the field of smoke and heat detection systems.

16. Economic impact and Improvement in competitive position

The employment of the new technology will maintain or, in some cases, acquire a strong market position against non-European competitors. In particular, new application fields which are in the hand of non-European competitors, such as fire protection in aircraft hangars and petrol stations are to be entered.

The expected economic assessment of the impact of introduction of the new technology on the business of Minimax is characterised as follows:

- improvement of competitiveness
- more profitable production
- higher quality standard
- resulting in sales increase of about 15%.

The projected quantitative impact of the application experiment is shown in Fig. 2.

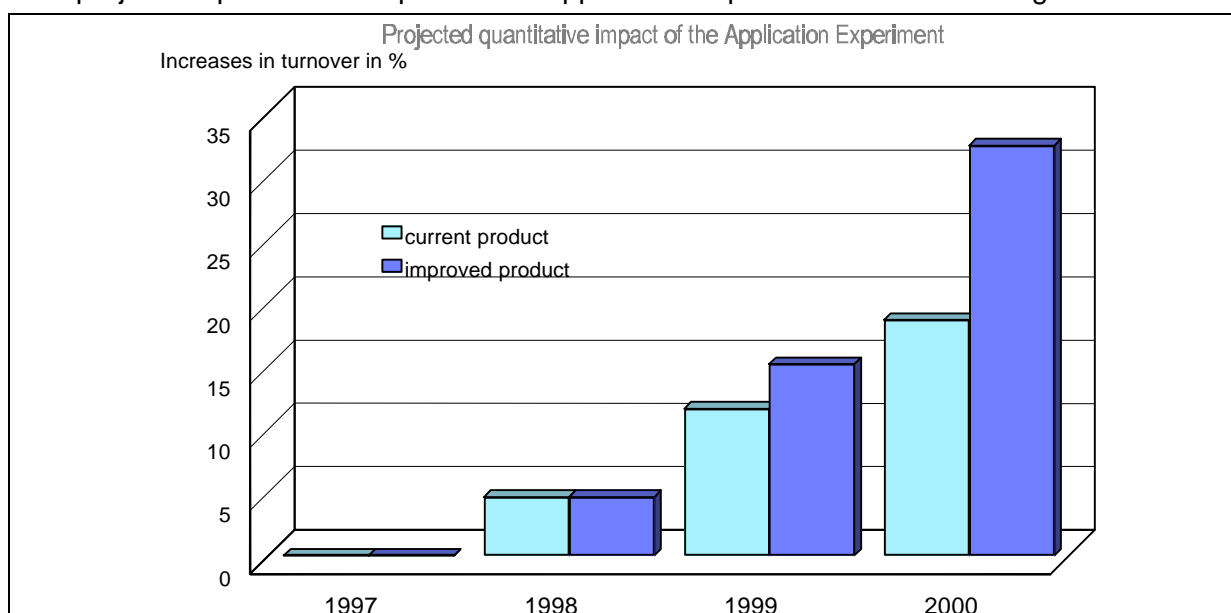


Fig. 2 Projected quantitative impact of the Application Experiment

The expected pay-back period of the project costs of 104,000 ECU is about 3 years through increased sales and reduced costs. The lifetime of the product is expected to be about six years. This will enable an ROI of about 250 %.

Minimax will remain very competitive, as the experience gained during the application experiment will be used to update other system components for fire protection, that are today build with conventional logic

The benefits for future users of Minimax products are:

- higher safety and reliability
- prevention of major damage with respect to human life, environment, industrial plants etc.

17. Target audience for dissemination throughout Europe

Classification of the AE according to the PRODCOM codes:

Instruments & Appliances for measuring, checking, testing etc.: 33

This AE is mainly of interest for companies, which are producing equipment with several sensor devices on a small size, e.g.:

- Companies working on industrial process control, especially in the chemical sector or other areas that need a very good fire protection
- Automobile industry and their suppliers
- Companies working in the area of signalling alarm systems, domestic applications and heating plants