# FUSE

Demonstrator Document

## MCM REDUCES COST OF CRYSTAL OSCILLATOR FOR COMMUNICATIONS EQUIPMENT:

Combining crystal and oscillator circuitry defends market share

**AE 24760**

**Project Summary**

SaRonix B.V. is a medium-sized Dutch company designing and manufacturing quartz crystals and oscillators for the general & industrial market, with sales of 20 MECU. The 200 persons work force includes some 15 professional electronic engineers (B.Sc. to Ph.D. level). The product line includes quartz crystals in metal or glass encapsulation; and a variety of quartz oscillators in metal encapsulation: clock oscillators; voltage-controlled oscillators; temperature-compensated oscillators; and combined temperature-compensated voltage-controlled oscillators. The product frequency ranges from 1 to 200 MHz.

The objective of the AE was to reduce the size of the quartz oscillator to an absolute minimum by incorporating the quartz blank and an oscillator IC die into a common, hermetic encapsulation in which the interconnection is integrated, i.e. a ceramic chip carrier with sealed lid.

The existing oscillators of SaRonix are built on PCB-type or hybrid carriers. They are large because of their through-hole leaded metal package, in connection with the hermetic sealing requirement of the quartz. They are expected to lose market share because most new applications capitalise on the concept of miniaturisation, e.g. mobile telephony, PCMCIA cards.

With the new adapted technology the through-hole version changes into true SMD; the SMD connections are integrated into the carrier; the carrier can be sealed hermetically without the need to seal the quartz in its own, separate housing. The size of the resulting product is only determined by the quartz itself. In addition, the cost price is reduced considerably because of fewer materials.

The economic benefits of this AE are a strong increase of sales quantity and profits. The capability of SaRonix increases with the design knowledge in a new, MCM technology and the option to apply this in manufacturing.

This AE had a duration of 13 months.  The whole project, including the investment in production machinery, cost 1250 kECU, of which 143 kECU was related directly to this AE. The payback period of the whole project is expected to be less then 18 months. Total return over an estimated life cycle of 10 years is estimated at 4.3 M ECU. The ROI is 344%. or 34.4% per annum.

The project has successfully been completed. SaRonix learned the design rules for ceramic chip carriers; how to implement a sensitive quartz crystal into this carrier; critical design parameters for the interaction of IC and quartz in an integrated small housing; critical process parameters for maintaining product quality. The experience is such that a manufacturing line could be installed.

***Keywords***

MCM, miniaturisation, crystal oscillator, cost reduction, hybrid, electronic component manufacturer.

## 1. Company name and address

SaRonix B.V.
P.O.Box 70
7000 AB Doetinchem
Netherlands

## 2. Company size

SaRonix B.V. has 200 employees, of which 40 are involved in electronics. The positions of these employees are: product marketing (3); product design engineer (4); process & software design engineer (3); design assistant (3); information systems (1); electronic maintenance (4); production assistance engineer (2); production & quality control (19); part of management (1).

Company sales amounts to about ECU 20M, of which 5% is in the area directly affected by the present experiment.

## 3. Company business description

Philips started the manufacturing and sales of quartz crystals in the early fifties, mainly for telecommunication applications. In 1968 the manufacturing moved from Eindhoven to Doetinchem, and the second main application area was the television market by then. Car electronics and electronic data processing became the next areas in the 80's and 90's. Quartz crystal oscillators became an important part of the product portfolio from the mid-80's onwards.

The Doetinchem factory has been part of the Philips business group Passive Components until April 1995, when Philips wanted to divest this activity because of its relatively small size. The name changed into SaRonix B.V. The majority of sales still takes place by the Philips Passive Components group under the Philips brand name, but in addition to that the SaRonix brand is being introduced by a new sales force.

SaRonix B.V. is now active in the business of Frequency Control Products, in particular quartz crystals and quartz crystal oscillators. The product line includes quartz crystals in metal or glass encapsulation; and a variety of quartz oscillators in metal encapsulation: clock oscillators; voltage-controlled oscillators; temperature-compensated oscillators; and combined temperature-compensated voltage-controlled oscillators. The product frequency ranges from 1 to 200 MHz. The main application areas are consumer electronics (TV, domestic appliances); car electronics; electronic data processing; network and telecommunication systems; control & measuring equipment. The company's activities cover the full area of Sales & Marketing, Design & Engineering, and Manufacture of quartz blanks & crystals & oscillators.

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

SaRonix is a major supplier in Europe with own manufacturing. Markets served with crystals and oscillators are in Europe, Far East, and USA.
For the oscillator concerned in this AE, the main market is at OEMs, in the USA, for data processing applying new HCMOS/ACMOS MPUs, CISC and RISC processors, and high-speed graphics. The small size of a ceramic enables users to make wireless & PCMCIA Gig-Ethernet and Fibre Channel cards. Several European OEMs buy imported oscillators.
The total market for this oscillator is estimated at about 20M units per year. The average growth is about 30 to 40 % per year for the frequency range under consideration. The SaRonix market share is about 0.5 %.

For the other oscillator products of SaRonix B.V., the total market is several 100M units per year and their share is about 2 %. For quartz crystals, the market size is several billion units per year and their share is about 2 %.

Major quantitative competitors (their market share indicated between brackets) in the field are in the Far East, like JVC (10%), TEW (5%), Seiko (20%), Kinseki (15%), and TXC (5%). Qualitative competitors are also located in Europe, like TQ (Oak), KVG (Vectron), and C-MAC, and in the USA, like Oak and Vectron. The competition is mainly manufacturing metal-encased or plastic moulded units, but ceramic units are appearing rapidly at JVC, TEW, Kinseki, TXC, and Vectron. Ceramic encapsulation per se is still more expensive than the other ones. If its potential smaller size can be fully utilised by integrating the electronic function as an IC, a cost benefit results.

For the oscillator concerned in this AE, competition is mainly manufacturing metal units. The position of SaRonix will be strengthened by the lower costs and further by the smaller size of the proposed oscillator and its surface-mount applicability. The market share is expected to double, whereas it would be decimated otherwise in the next 5 years.

The sales history of the current metal product, subjected to this AE, is given below:

| Current Product | 1995 | 1996 | 1997 |
|---|---|---|---|
| sales quantity | 70k | 90k | 100k |

**5. Product to be improved and its industrial sectors**

The existing product is a PLL- type clock (Phase Locked Loop Crystal Oscillator). This comprises 6 components: a quartz crystal, HCMOS integrated circuits for oscillating and output buffering, and decoupling capacitors. These are assembled together on a hybrid circuit in a metal housing that is dry-nitrogen filled and hermetically sealed by resistance welding. The package has four connecting pins, for supply voltage, ground, non-connected and output frequency. Pin spacing is compatible with 14-pin DIL (Dual in Line) packages.

Important product characteristics are summarised in the following table:

| | |
|---|---|
| Housing | DIL14, through-hole leaded device |
| Dimensions L x W x H | 20,4 x 12,7 x 6,6 mm |
| Construction | Hybrid module on metal/glass base |
| Frequency range | 70 to 135 MHz |
| Supply voltage range | 5,0 V ± 5% |

The quartz crystal is relatively large; its construction limits the reliability as expressed in mechanical and temperature cycling stability. In addition, the 5V-supply voltage is not satisfactory any more in view of demands for power reduction in association with 3V battery supplies. These aspects rule the present product out for most mobile applications. The product’s application is in electronic data processing and in networking. Without innovation, the present product’s sales would be halved and its market share diminish from 0,5 % to less than 0,2% in 3 years’ time.

The old product with the removed metal lid is shown in figure 1, together with the new product; they can be compared with the size of a Dutch guilder.

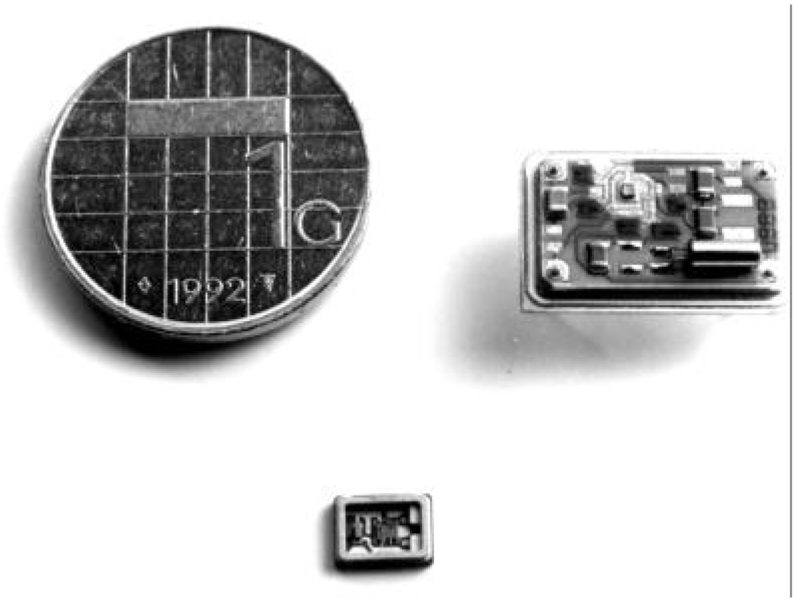


Figure 1: The old and new product without lid.

**6. Description of the product improvements**

The product to be designed is the PLL-XO type "Cerox." It will comprise a quartz crystal blank, one HCMOS integrated PLL circuit for multiplication, oscillating and output buffering, and a decoupling capacitor.

These are assembled together on a ceramic chip carrier with metal lid. The housing is dry-nitrogen filled and hermetically sealed by seam welding. The package has connecting flats for supply voltage, ground, output frequency and one, which is non-connected. Connection spacing is compatible with the QIAJ (Quality & Industrial Association of Japan) package series for crystal units and clock oscillators.

The most important differences with respect to the existing product are the small size: reduced from 1700 to 67 $mm^3$; and the SMD-housing on its own instead of leads for through-hole mounting. This greatly enhances the product's potential for application in miniaturised equipment. An additional advantage is the option for low-power applications by offering 3V supply voltage: the power drain decreases from 275 mW to 90 mW
Besides these customer benefits, SaRonix will achieve a 60% cost price reduction for this renewed product as well.

The characteristics are summarised in the following table:

| | |
|---|---|
| Housing | real SMD device |
| Dimensions L x W x H | 7,2 x 5,2 x 1,8 mm |
| Construction | Ceramic chip carrier with welded lid |
| Frequency range | 80 to 125 MHz; optional up to 135 MHz |
| Supply voltage range | 2,7 to 5,5 V |
| Control voltage range | 0,5 to 2,5 V |

The industrial sector does not change, but the small size of a ceramic enables users to make wireless & PCMCIA Gig-Ethernet and Fibre Channel cards.

## 7. Choice and rationale of selected technologies and methodologies

### 7.1. Technology

The present PLL-XO contains digital ICs and a quartz crystal blank, assembled together on a hybrid, on a metal base having leads through glass-bead sealing. The oscillator is sealed hermetically with a metal can, by resistance welding.

The principal objective is to reduce the volume of the oscillator by at least an order of magnitude, while going to a real surface-mount version.

One fabrication option is to assemble ICs and hermetic quartz crystal on a lead frame and encapsulate the assembly with epoxy compound. This way, the frequency of the quartz crystal has to be accepted as received, while a deviation (offset) of the crystal frequency will occur because of the actual capacitive load of the module. In addition, this would require a very small and pressure-insensitive quartz crystal: typically a tube-like crystal. Both effects effectively limit the electrical performance of crystal oscillators: the total frequency tolerance of the oscillator will be in the range of ±50 ppm at its best (including crystal calibration, offset, and ageing effects).

The other option is to stay with MCM technologies. A first option would be to apply a printed-circuit board, onto which a quartz crystal is soldered along with the other components. In this way, the size of the module would not be less than the present one, since the crystal itself needs to be hermetically sealed to avoid contamination by vapours from the PCB. Therefore the drawback of frequency mismatch, mentioned above, would not be removed.

The option is to replace the hybrid & metal base by a ceramic chip carrier. Since this housing is hermetic by itself, it no longer requires a crystal that is hermetic but it can do with a quartz blank only (the plate that is actually vibrating within the quartz crystal). The size of the oscillator would be determined by its largest component only, i.e. the quartz blank. All other parts, i.e. the ICs and the capacitor, would fit in the space left between quartz blank and chip carrier. It requires the ability to design the chip carrier, master the component placement techniques, and seal the ceramic carrier.

### 7.2. Cost benefits

By the technology chosen the general production cost is reduced partly by the lower direct cost of the ceramic carrier (hybrid now ECU 2, ceramic carrier after the experiment ECU 0,50). Another part can be reached by material size and by handling efficiency in larger quantities: for the PLL-XO under consideration. These additional savings come from the use of a less expensive crystal blank (typically ECU 0,12 instead of 0,25) and the option of automated blank placement (typically ECU 0,02 instead of 0,25).

### 7.3. Methodology

The design methodology consists of the electronic circuit part and the layout part. For the electronic circuit design they use the SPICE simulation program in its full functionality, and apply this to simulate the specific oscillator designs. For the layout design, three possible software programs, Cadelec, Ulticap/Ultiboard and Autocad were considered. Autocad is of general drawing use; it is universal for all applications but does not have specific utilities for electronic circuits. Cadelec is an addition to Autocad, best used for electrotechnical hardware like control panels. Ulticap/Ultiboard offers a direct relation between electronic circuit and layout and is the preferred software. The layout of the ceramic chip carrier is relatively simple and the subcontractor Hymec has experience with reading in designs made with Autocad, while SaRonix has experience with Autocad as well. That’s why this tool is chosen for the layout. The layout is shown in Figure 2.

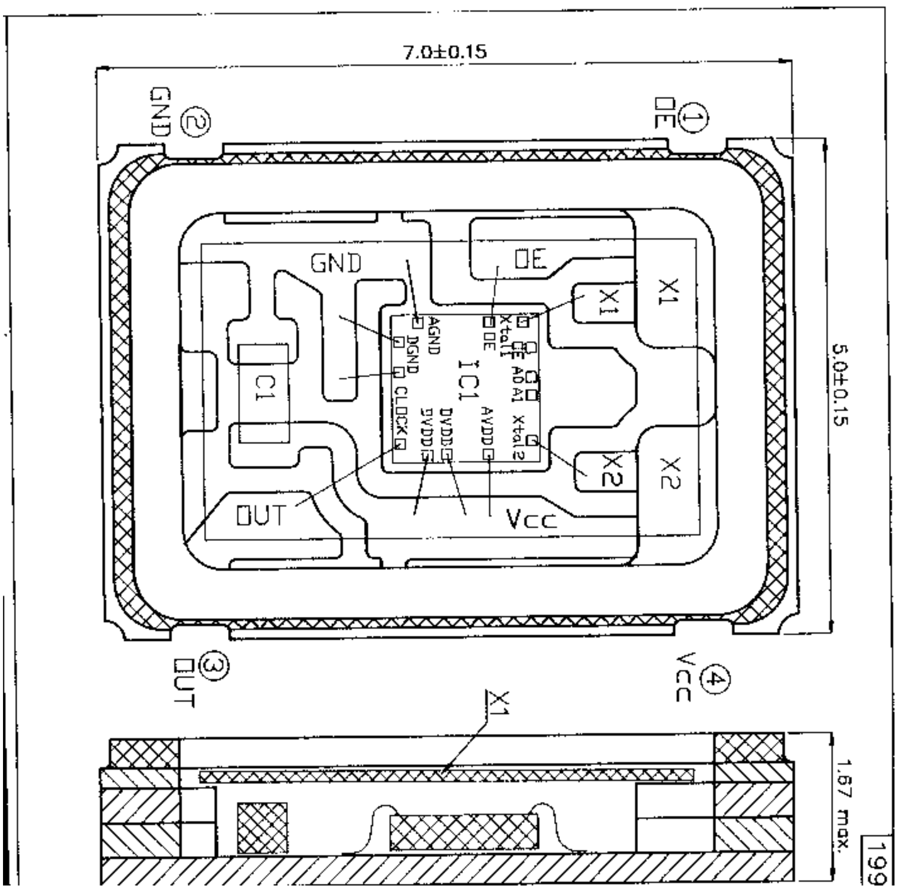



Figure 2: Schematic of the MCM carrier

The test methods envisaged for the experiment comprise a selection out of IEC standard tests (IEC 679-1, "Quartz crystal controlled oscillators"; IEC 68-2, "Recommended basic climatic and mechanical robustness testing procedure for electronic components"). As an addition, ESD sensitivity testing is envisaged. These tests are standard requirements in this industry.

## 8. Expertise and experience of the company

SaRonix B.V. has over 20 years experience in designing and manufacturing quartz crystals, as well as those quartz crystal oscillators that are built on PCB-type or hybrid carriers, and sealed by resistance welding or soldering. They are well aware of the requirements for surface-mount application (like reflow conditions, resistance to soldering heat). They have much experience in automatic and semi-automatic pick-and-place, assembly, laser scribing, hermetic encapsulation, and measuring operations over temperature; as well as all operations relating to quartz blank manufacturing. The staff selected for participation in the AE is specifically experienced in electronic and mechanical design of oscillators; assembly & sealing engineering; test & measuring.

SaRonix has no experience in designing, applying or sealing ceramic chip carriers. They have no experience in naked-die bonding and wire bonding.

Table 4 shows the experiences of the team, which worked on this application experiment.

| FUNCTION | FORMER EXPERIENCE |
|---|---|
| R&D Manager | Works at SaRonix for more then 10 years, knows a lot of materials used for producing crystal oscillators and has a long managerial experience in design & technology. |
| Senior electronic engineer | Works at SaRonix for more than 10 years, has a wide experience with crystal oscillator electronics and products |
| Electronic product engineer | Just graduated from University with specialisation in HF electronics and IC design |
| Mechanical equipment engineer | Works at SaRonix for 3 years, with much experience in equipment design and product handling |
| Physical product & process engineer | Works at SaRonix for 8 years and has a wide experience in product encapsulation, adhesives, and sealing. |
| Development assistant | Works at SaRonix for more than 10 years in oscillator manufacturing and development departments |
| Development assistant | Works at SaRonix for more than 10 years in assembling and development departments |

Table 4: Experience of the team

## 9. Workplan and rationale

The workplan was set up in such a way that the maximum of knowledge transfer was realised without delaying the project unnecessary. Since SaRonix needed to establish their own production line, knowledge transfer was the key word, during the project. The main roles of the subcontractors were to provide their know-how and to produce prototypes. The original workplan consisted of the following tasks:

9.1. Project management, reporting & dissemination

**Tasks:** project planning; project team formation, coaching & management; budget management; consultations with subcontractors; project survey preparations; reporting; presentations. By SaRonix.
**Costs:** 7.5 KECU (22 man-days at SaRonix).
**Duration:** 10 months.

9.2. Component specification phase
**Tasks:** collecting data from the market (customers & competition & technological trends). Establishing the kind of product to develop. Drafting a provisional spec for discussion purpose. Adapt and draft a target spec. By SaRonix.
**Costs:** 24 KECU (120 man-days at SaRonix).
**Duration:** 1 month.

9.3. Technical specification phase
**Tasks:** Translating the component specification and the technical rules and constraints into a technical specification. Drafting a provisional technical specification for discussion purpose. These tasks are performed by SaRonix with assistance of the subcontractors.
**Costs:** 24 KECU (120 man-days at SaRonix); 9 KECU (subcontractors).
**Duration:** 1 month.

9.4. Training effort
**Tasks:** general MCM-technology training not included in any of the following specific tasks. Information and documentation is supplied by subcontractors. SaRonix consolidates the training into a set of design rules for the application of MCM technology to quartz crystal oscillators.
**Costs:** 2.5 KECU (7 man-days at SaRonix).
**Duration:** 1 month.

9.5. MCM design
**Tasks:** design, simulation & bread-boarding by SaRonix; design assistance and feedback by subcontractors resulting in full & unambiguous product and materials specifications.
**Costs:** 11 KECU (40 man-days at SaRonix); 5 KECU (subcontractors).
**Duration:** 5 weeks.

9.6. MCM assembling
**Tasks:** actual assembling and training on the job by subcontractors to SaRonix. Evaluation of handling problems. Resulting in open oscillator modules and assessment of manufacturability.
**Costs:** 11 KECU (40 man-days at SaRonix); 10 KECU (subcontractors).
**Duration:** 8 weeks.

9.7. Module sample sealing
**Tasks:** actual sealing and training on the job by subcontractor to SaRonix. Evaluation of process parameter settings. Resulting in ceramic encapsulated samples for evaluation.
**Costs:** 7 KECU (25 man-days at SaRonix); 5 KECU (subcontractor).
**Duration:** 8 weeks.

9.8. Prototype testing

**Tasks:** electrical and mechanical testing, analysis and evaluation by SaRonix; feedback to subcontractors. Resulting in reports of tests for product specification and documentation.

**Costs:** 16 KECU (60 man-days at SaRonix).

**Duration:** 8 weeks.

9.9. Process set-up

**Tasks:** full process design and instructions by SaRonix. Evaluation of critical parameters in order to prepare for Statistical Process Control. Assistance by subcontractors. Resulting in specs for manufacturing processes.

**Costs:** 22 KECU (80 man-days at SaRonix); 5 KECU (subcontractors).

**Duration:** 12 weeks.

9.10. Final qualification testing of the ceramic oscillator

**Tasks:** execution of tests according to IEC standards. Use of electrical test equipment for initial testing and testing in the temperature range of specified electrical parameters. Use of climatic and temperature cycling equipment for robustness tests. Application of ESD testing. All by SaRonix; resulting in release report on the oscillator, for customers and manufacturing.

**Costs:** 18 KECU (65 man-days at SaRonix).

**Duration:** 9 weeks.

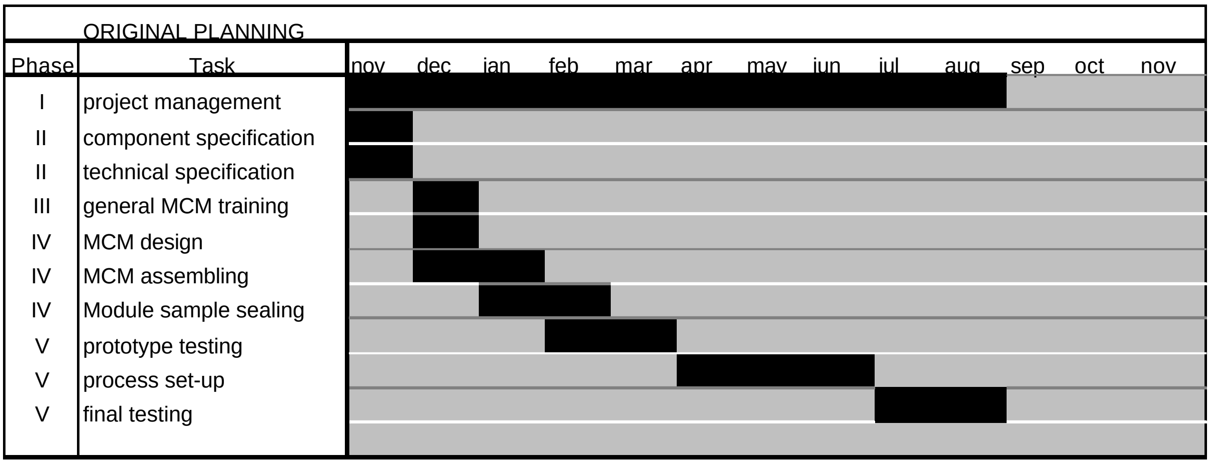
**Risk analysis at the outset:**

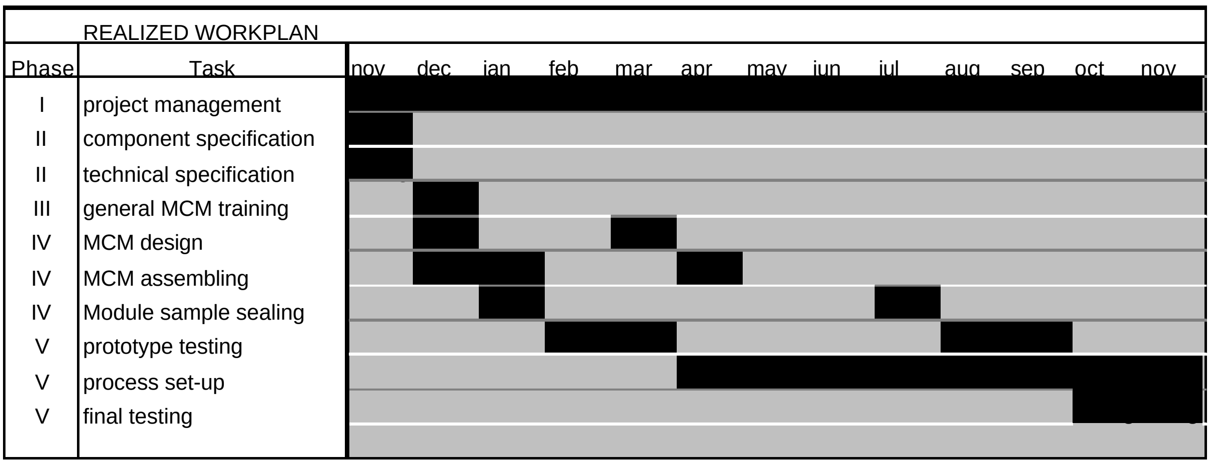
From a technical viewpoint, a major risk is the compatibility of the material and components used to the environmental conditions during manufacturing at SaRonix and during reflow soldering at the customer's application. The quartz crystal blank is very sensitive to mechanical stresses and to pollution; the IC bonding and wiring was reported to be sensitive as well.
If this could not quickly be solved, it was envisaged to start with a less performing new product and improve its performance at a later point on the learning curve.
To minimise this risk, an option list was made of alternatively applicable materials (adhesives in particular), to be investigated for final selection. As an option, metal springs were considered for the quartz crystal blank attach. For the potentially critical processes (annealing and sealing in particular) a range of process conditions was to be investigated.

From the viewpoint of technology transfer, a major risk was allocated at the subcontractor's unwillingness to co-operate whole-heartedly.
To cope with this potential problem, additional potential subcontractors were selected and a route was envisaged to work through the equipment suppliers.
The risk was minimised by including a search for new subcontractors and, mainly, equipment suppliers all over the world.

**Actual workplan:**

The actual workplan did not differ from the original one as far as contents are concerned. The time planning did differ, due to the fact that the oscillator specification had to be revised to get the market acceptance. An assessment report on the first and the revised oscillator spec was made. In addition, a redesign was necessary, introducing an additional delay. During the redesign a lot of additional knowledge about processing equipment was gained and contributed to the successful introduction of the product line. The redesign phase allowed the process set-up phase to take longer. This made it possible to look in more depth into all aspects of the process and machinery.




With the main subcontractors Hywel Connection, Hymec, and Rood Technology the interfacing took place by the following general procedure:

1. Agree with the subcontractor's management on the start of the co-operation. Settle a Non-Disclosure Agreement and take care to keep the confidentiality agreement also to third parties like the final customer.
2. Establish the main contact partner for technical communications and arrangements.
3. Arrange extensive meetings at the subcontractor's site, to discuss the project requirements and to assess the possible technical contributions by the subcontractor. Invite as many technical attendants as possible and let them participate in the discussions with their comments and advice's.
4. Perform experiments and test runs at the subcontractor's site, by his personnel first, and by own engineers later. Training to be given on the job to our engineers, in such a way that they can

understand and operate the various design programmes, software, equipment, etc. Ask for any and all information on programmes, design rules & experience, parts, equipment, suppliers.

5. Invite the subcontractor's representative back to own site to present and discuss results. Involve own purchasing officer (supply base manager) regularly.
6. To keep the subcontractor involved in the project, issue engineering orders that cover part of his costs.
7. Settle a production forecast for him together with the purchasing officer: first production runs will allow him to get some return on the investment he made by his training efforts. Keep him informed of proposed changes that affect him. Give him your open opinion on his performance and allow him to give feedback on changes (new bid, other options).

## 10. Subcontractor information

### 10.0 Specific requirements

Subcontractors need to have experience in any or more of the following areas: hybrid assembling; IC-die attach and wire bonding; hermetic sealing; seam sealing; high-temperature hybrid materials. A high level of the technical staff would be beneficial to discuss and solve the problems posed by a ceramic carrier and the higher temperatures., and also to get some more co-operation in general.

### 10.1 Hywel Connection at Doetinchem, Netherlands

Hywel Connection has over 10 years' experience relating to design and manufacturing of heavy-duty hybrid modules for high-temperature applications at small and mid-size companies. They are in full control of the MCM technology such as screening the hybrids, pick-and-place components, die and wire bonding.
Recently they moved to a much larger location at 'sHeerenberg, Netherlands.

Advantage: nearby location, easy contact. Willingness to perform development trials.
Disadvantage: because of work overload, their engineering staff had limited capacity available, causing long throughput times. No seam sealing available. Pricing on the high end for a larger scale of production of very small modules, due to lack of automation.
Nature of the contract: not eager to participate in big projects; prefer small steps and paid orders rather than a glorious forecast.

### 10.2 Hymec at Sittard, Netherlands

Hymec also has over 10 years of experience designing and manufacturing heavy-duty hybrid modules for small and mid-size companies. Hymec's experience relates to microelectronics and hybrid technology for medical and high-end industrial use. They are in full control of the MCM technology such as screening the hybrids, pick-and-place components, die and wire bonding. Hymec has the added knowledge of seam sealing packages. They have small-power seam-seal equipment available.
Their engineering staff has made helpful recommendations in the past. They are willing to participate in joint projects involving grants or subsidies.. At present, they have been taken over by Neways, Nuenen, the Netherlands.

Advantage: location not too far off; easy contacts due to long-lasting business relation. Wide scope of materials and equipment, including seam sealing.

Disadvantage: some reluctance to technology transfer which might damage their new turnover at us. Getting too expensive for our kind of market.
Nature of the contract: open-end co-operation, with modest bills afterwards.

10.3 Rood Technology at Alton, Hampshire, England

Rood Technology was added as a subcontractor during the course of this AE to fill a gap. Their experience relates to industrial-scale engineering and manufacturing of MCMs, in particular die and wire bonding. Their industrial experience (and pricing) is attractive when compared to Hywel Connection and Hymec.
At first, the Paris plant was involved in the AE. When this was closed, Rood England took over very smoothly.

Advantage: pricing structure; willingness to enter new markets, at first (due to business problems).
Disadvantage: not a stable partner, too much problems of their own. Not much specific technical know-how for our specific kind of product.
Nature of the contract: few experiments, more regular sample orders.

10.4 Hollandse Signaal at Hengelo (Ov.), Netherlands

Hollandse Signaal was added as a subcontractor during the course of this AE to fill a technology gap. They are engaged in the field of professional and military systems, where seam sealing is applied. They have expertise and equipment available for the purpose of learning parameter significance in seam sealing. The seam sealer of Hymec turned out to be not powerful enough to seam-seal the prototypes. Therefore, the equipment of Hollandse Signaal was used, despite of their high price.

Advantage: specific seam-seal know-how, and willingness to share it.
Disadvantage: required some more planning of experiments to fit in their regular plans.
Nature of the contract: open-end support with experiments; bills afterwards.

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

Knowledge barriers:

The marketing perspective is a main issue. What is known are products supplied by competition and a few inquiries by potential customers on similar products. In particular the European customers appear to have no strategy for component development. Their only intention is to get a European source for those products that they already purchase from Far East (at preferably the same price). Since the Far East sources for those products have already progressed on the learning curve and expanded their capacity, the economic risk to start in the same area is too high. SaRonix must start with a new product, having at least some features that are not (yet) available from Far East. This presents a marketing barrier, at least in Europe.

Cultural and inertia barriers:

SaRonix feels they have to engage in the new product area, but they still face a lot of problems asking for solutions in the existing (old) product & process area. This creates difference of opinion between "innovators" and "improvers". In particular the manufacturing staff is reluctant to support new developments while the production processes are not as good as they could be.

Technology barriers:

The major barrier is the lack of experience with the ceramic technology. While it is felt that a lot of knowledge can be gained from the subcontractors, it is feared that an appreciable gap will remain when it comes to mastering the details. The essential expertise in quartz devices concerns the control of processes to reach the narrow variation of product properties that the oscillator market requires.
SaRonix had neither knowledge of ceramic carriers, neither the mechanical nor the electrical aspects of their use. Mechanical aspects meant are the sealing techniques (power, heat dissipation, stress induction). Electrical aspects meant are the kind of components that could be applied and the way of mounting them (IC die attach, wire bonding; small component placement).

One of the major technical problems, in which this AE differs from other MCM AEs, is the problem of contamination of the crystals. Contamination of crystals is deadly for the function (steady frequency) of the oscillators. That's why the crystals are always hermetically sealed. The MCM itself contains different kind of materials, possibly affecting the performance of the crystals. Moreover, the assembly process is normally done in an environment with various nasty gasses. This can also cause contamination of the crystals.

Human resource barriers:

The AE as such can have no value when its results are not transferred into manufacturing. This requires additional engineering, and equipment investments. The management is aware of the importance of the project and internal budget is raised for both implementing designs as well as investing in the production line. Additional engineering needed to be found.

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

Knowledge barriers:

*Feasibility phase:* to test the marketing perspectives, a full specification has been drawn up and discussed with several marketing representatives as well as a few potential customers (in Europe). This pertains to a ceramic product with a specification that is not yet available from competition: it has a higher potential functionality, but also a larger size than the smallest available oscillators in the market.
The outcome of the discussions was negative. Then a wider marketing perspective was chosen, by involving USA representatives and their customers. The specification was altered. It still was to be a ceramic oscillator, but the functionality was different: less potential features, but smallest size compatible with competition. This gained approval.

*Implementation phase:* Datasheets of the future product were sent to potential customers. SaRonix got sample inquiries for specific products and frequencies that proved that the strategy is right.

Cultural and inertia barriers:

*Feasibility phase:* no simple solution could be found for the conflict of interests, in the priority between optimising the old production process or developing a new production process. Persuasion by the management team that the new product introduction was necessary for the future of the company was reluctantly accepted.

*Implementation phase:* the capacity allocation to this project causes indeed problems elsewhere. A workers' flexibility program has been agreed upon that expands the working week from 36 to 45 hours for a defined period, for the engineers under consideration.

<u>Technology barriers</u>:

*Feasibility phase:* the search for experience with the new technology has been extended beyond the scope of the subcontractors in the AE as far as possible. Travels were scheduled to suppliers of materials and equipment and getting their experience at servicing other customers, preferably SaRonix's competitors. This is not considered too unethical by these suppliers as long as they think these competitors to be unaffected by SaRonix. This is more or less true when they are larger and located in other areas (USA, Japan).
Next action was to exchange the information gained from suppliers with the subcontractors and to learn from the experiences.

*Implementation phase:* getting full control of details is included in the implementation phase, by using the expertise on SPC methods from current manufacturing. Care is taken not to overload the engineers by accepting commitments for narrow-tolerance parts in this phase.

<u>Contamination</u>:

The contamination problems had to be tackled with previous knowledge about materials, which are used for the old oscillators. If new materials, gasses, adhesives, fluids and rubbers are to be used, these materials are compared with existing materials in order to estimate the risks. Also a lot of information is obtained from the suppliers of the materials and equipment. Still, some experiments need to be done and some risks are foreseen in the planning.

<u>Human resource barriers</u>:

*Feasibility phase:* full investment plan has been drawn and agreed upon by management.

*Implementation phase:* to secure the progress, additional engineering capacity has been hired on temporary basis, to support the process engineering. This enabled the engineer in this team to concentrate more on this application experiment. Moreover, their working weeks were expanded from 36 to 45 hours for the duration of this AE.

## 13. Knowledge and experience acquired

The new product incremental to the SaRonix line is an oscillator having the smallest presently possible size and providing a true SMD outline.

The experience gains are summarised in the following listing:

- In the feasibility phase, SaRonix learned the importance of the specification issues, discussed with potential customers. They could assess the details needed for successful oscillator development.
- The technical training & learning extended throughout all phases by the application of concurrent engineering principles. It provided SaRonix with the knowledge to design oscillators involving MCM circuit technology in general, and in particular to design ceramic chip carriers in surface-mount versions.
- In the implementation phase, SaRonix gained process knowledge to be now able to manufacture the ceramic oscillators.
- Now, new designs for customers can be managed in a tighter and predictable time frame, since a knowledge base for the new technology is established.
- During this AE SaRonix expanded their subcontractor list appreciably.

## 14. Lessons learned

To product definition & specification:
A technology push for a new product should rank the most important parameters, like in Quality Function Deployment, to get market acceptance. When aiming at a miniature component, size is most important. Increase of size beyond a certain market standard cannot be balanced by added electronic functionality.
Nothing can beat the impetus of a customer involvement. While this may be wished as an order or letter of intent, market reality demands the supplier to take most of the risks. This risk can be reduced by following the technological trends as close as possible. Without customer involvement, the internal company dynamics bear the risk of being too much determined by technical opportunities.

To subcontractor selection:
In this specific case, the major part of knowledge was gained from discussions with outside-Europe suppliers and comparing their information with the knowledge of their European subcontractors.
At the start of the AE, the subcontractors were chosen from the ones with which SaRonix had already some working relation in the MCM field. While this may confine the technical horizon, it lowers the organisational & personal barrier to start a common project.
However, during the course of the AE, more subcontractors were approached than planned before; the knowledge level and business ambition of every individual one appeared insufficient for successful completion of the AE. Combining information proved to be in everyone's advantage. It cannot compensate the lack of ambition at a particular subcontractor.
For this AE, it turned out that the suppliers of parts and equipment know more than the subcontractors know (or are willing to give away).
Do not hesitate to approach more suppliers, even those that you probably will not buy from. They can give interesting information.
Maintain a good relationship with suppliers and subcontractors. When asking for information or help, explain your situation but do not make promises you cannot keep. For prospective suppliers of parts and equipment the possible benefits in supporting you are obvious; if you do not continue business with them, just explain. For subcontractors, the situation is knotty: the extreme consequence of the AE may be to put them out of work for you. Explain that, whatever happens, it happens because of economic rationale and eventual inevitability; and the AE is to raise the level of technical intelligence and business all together.

To experimental set-up and technological alternatives:

New processes had to be learned, for which new equipment had to be purchased; some of which were quite expensive. It proved extremely valuable to have all processes available on a small production scale before and even while the new equipment was acquired. In cases where no equipment was yet available at their premises, the equipment at the subcontractor's location was used. SaRonix learned not to be modest when it came to exercise pressure on the subcontractors, and this was of great advantage to SaRonix. It also revealed the subcontractor's ambition better than before, helping them in making the selection.

## 15. The future: Industrialisation and internal replication

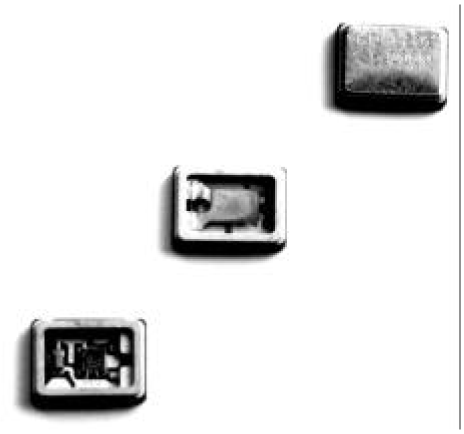


Figure 3: The new SMD Crystal oscillator at different stages in the product line.

This AE has been carried through to such an extent that SaRonix B.V. has now almost completed an industrial line for volume production of ceramic oscillators. Part of the subassembly is contracted out (die and wire bonding), but may be added to the line in a later phase if this would present logistic advantages. Figure 3 shows the product in different stages in the product line. Volume production will start at the end of 1998.

Total development & engineering costs for the new product line amount to about 250kECU. The AE costs are 143kECU, covering the product development and the process set-up. The balance of 107 kECU has been spent on engineering: machines & tools detail specification, manufacturing layout, installing and running-in the equipment. This part of the work started halfway the product & process development, then ran in parallel to it for about 6 months, and was extended after the completion of the AE for another 6 months. Total additional equipment investment costs for the above quantities are about 1000 kECU. This equipment can be used for the production of other types of ceramic oscillators, as well.

Samples are sent to customers on a weekly basis and production planning is ramping up. Market projections with comparison to last year cannot yet be observed. All background and design knowledge to the technology applied is present within this team in the company. In order to transfer it to more people within the company, it is preserved in the form of machine & process files, and in the set of design rules collected in this AE.

As a follow-up of this AE, the following product families will be developed:
- Extension of the range of the present PLL-XO to a wider frequency range, in the second quarter of 1998. The currently developed range covers only the GSM, DECT Ethernet and FDDI area.
- Other oscillators in the same size but with different functionality in the second part of 1998;
- Smaller devices in the next year.

In addition to this, an active search will be continued to find other combinations of IC and quartz crystal into a ceramic oscillator.

## 16. Improvement in competitive position

The economic benefit of the new technology for the PLL-type quartz Crystal Oscillators is presented in the following table, for the frequency range of 80 to 135 MHz.
Without a ceramic alternative, the current metal product was expected to show a yearly sales increase of about 10% in quantity, at a slowly decreasing sales price. The ceramic alternative would push down the sales quantity and price of the metal units. Vendors of the ceramic product would gain market share over vendors of the metal product. The table reflects the situation for SaRonix: without this FUSE, SaRonix would be a metal product vendor and suffer loss of market share as well as profit. Being among the first suppliers of ceramics, SaRonix is able to gain both share and profit.

| | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|
| sales quantity | 90k | 100k | 90k | 70k | 50k |
| sales value, relative | 100 % | 94 % | 77 % | 54 % | 34 % |
| sales profit, relative | 100 % | 91 % | 69 % | 50 % | 30 % |
| New ceramic product | 1996 | 1997 | 1998 | 1999 | 2000 |
| sales quantity | 0 | 0 | 100k | 200k | 350k |
| sales value, relative | | | 60 % | 103 % | 149 % |
| sales profit, relative | | | 83 % | 133 % | 175 % |
| Market share, total | 0,6 % | 0,5 % | 0,7 % | 0,8 % | 0,9 % |

Note to the relative sales value and sales profit figures: they are given as a percentage of the actual sales value and profit for the current metal product in 1996, set at 100%.

In the final product cost the ceramic carrier makes up for ECU 0,50, compared to ECU 2 for a hybrid-on-metal carrier. Additional advantages depend largely on the scale of production automation, which is not part of this AE but necessary to be able to produce the projected quantities at the projected costs. Total development & engineering costs are about 250kECU of which the specific AE costs are 143kECU. Total additional equipment investment costs for the above quantities are about 1MECU. This equipment can be used for the production of other types of ceramic oscillators, as well.
The specific cost reduction of the ceramic carrier (at a lower cost of ECU 1,50) would be 150 kECU in the first year of producing 100k units and 300 kECU in the second year, followed by 525 kECU in the third year. Since the depreciation of the equipment is already included in the cost price, only the development and engineering costs have to be taken into account. Therefore the payback period will be less than 18 months.

Total return over an estimated life cycle of 10 years is estimated at ECU 4,3 The ROI is 344%. For the purpose of this calculation, the new ceramic product may be considered totally incremental to the sales. If it not been offered by SaRonix, then competition would have taken its share at some point in time, to the effect that the sales of the metal product would have decreased in the same way.

In addition to this, the new technology can be applied later to other quartz crystal oscillators like the simpler clock oscillator and the more elaborate voltage-controlled & temperature-compensated oscillator. Further extensions can be forecasted to even smaller designs, like packages of 3.5 x 6 mm.

Labour costs are much higher in Europe than in the Far East. Therefore, Europe is not the place to produce labour-intensive products. SaRonix rule of thumb is: If labour costs exceed 20% of the total costs of a product, do not produce this in Europe, since you will not be able to compete.

**17. Target audience for dissemination**

Following is a list of processes and skills learnt during this experiment:
- selecting ceramic chip carriers (having walls higher than the base plane);
- die & wire bonding of ICs on these carriers;
- pick & place of 1005 (0402) size components on the same;
- selecting and dispensing high-temperature adhesives on the same;
- positioning of quartz crystal blanks on the same;
- seam sealing of ceramic carriers with metal lid;
- design of reflow-solderable surface-mount oscillator with IC and quartz crystal blank on minimum distance, for elevated frequencies (up to 135 MHz).

The results of this AE will be of interest to companies:
* active in manufacturing MCM as part of their products, who may consider replacing hybrids by new ceramic carriers, available in a large variety of sizes;
* active in hermetic sealing of devices including electronics, to combine parts of the circuitry.

The design rules contained in this AE concern not so much the electronic circuit *per se*, but more the design of lay-out, packaging, environmental stability, and manufacturing and handling of the electronic part; to improve form, fit, and function.

The results pertaining to subcontractor and supplier search will be of general interest to small and medium-sized companies in electronics, materials and equipment.

The following sectors can be mentioned as target audience:

| Prodcom code | Description |
|---|---|
| 32XX | Electronic components and Tele, audio and video equipment |
| 33XX | Precision instruments |