DEMONSTRATOR DOCUMENT

FUSE Application Experiment 25970

A MAGNETO RESISTIVE MICRO-SENSOR SYSTEM FOR ENCODER APPLICATIONS

Abstract

FRITZ KUEBLER GMBH - ZAEHL- UND SENSORTECHNIK was founded in 1960. It now has 120 employees and designs, manufactures and sells worldwide electromechanical and electronic counters, message displays and encoders. Encoders are sensors used in motion sensing applications where angular displacements and distances are measured (e.g. robotics).

The objective of the AE was to improve the encoder product line in both performance and cost by using a microfabricated sensor and higher integrated electronic technologies. In addition Kuebler wished to acquire the necessary expertise to repeat the development process on future products.

The existing encoder products are based on opto-electronic components, including photodiodes, LEDs, SMT and glass scales encapsulated in a mechanical housing, together with surface mount electronics. These encoders are costly to manufacture and assemble, and are sensitive to EMC, high temperatures, shocks and vibrations, dust and water.

The new sensor system developed under this AE consists of a magneto resistive bridge array which is sensitive to magnetic fields, a mixed signal ASIC for signal processing and a magnetic scale. This can work up to 125°C and is not sensitive to EMC, dust and water. Further it costs around 50% of the existing product, and is suitable for mass production. A mixed signal ASIC was chosen in preference to a DSP because it would meet the performance criteria at a lower unit test, and the development cost using MPW were compared.

The new product has none of the technical disadvantages of its predecessor, and is more cost-effective and suitable for mass production. The cost of the new product will be around half that of the existing product.

The main lesson that Kuebler learnt from this AE was that for development projects such as this it is essential that the sub contractor is fully supportive. They also learnt that using the low cost method of developing a mixed signal ASIC using MPW from a foundry increases timescales.

In the AE the overall cost was 94 K ECU, and included the development of both the sensor and the mixed signal ASIC. The project took 15 months as proposed to the 12 months planned. The FU will spend an additional 100K ECU and a further 9 months to productionise the product and expects a payback period of 6 months for the AE investment alone. The ROI will be at least 30 times the AE investment assuming a 4 year life of the product.

1. Company name:

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2. Company size, personnel involved and expertise & experience prior to the Application Experiment

There are 120 employees within Kuebler. The company has expertise in the design of optoelectronically-based encoders, electronic and electromechanical counters and tools for injection moulding machines. In addition there is knowledge on optoelectronics, microcontroller programming, PCB layout and surface mount technology.

One encoder system engineer was involved through the whole AE, acting as the project manager. In addition, other specialists were involved when and where necessary. These included a mechanical engineer, production manager, and sales manager from the marketing department.

3. Company business description

Founded in 1960, Kuebler, with 120 employees of which 10 are engineers, designs, manufactures and sells electromechanical and electronic counters, message displays and encoders. There are in-house engineering facilities for electronic (PCB-layout & routing) and mechanical CAD and test equipment for EMC-tests, sealing tests (e.g. water proof), climatic tests. Nearly all the engineering is done in-house. In 1996 their turnover was around 6M ECU.

There are 3 R & D groups, one for each of the 3 product sectors, namely electromechanical counters, electronic counters and encoders. The largest group is for the encoders since this seen as the major future growth area for the business. In the encoder R & D group there are 7 people.

Kuebler offer all their customers counters and encoders designed and manufactured to their exact specification. This means that Kuebler have a large number of each type of product going through their production facility at any one time. It also means that their lead-time from concept to production needs to be as short as possible.

The production facilities consist of two pick & place machines and two solder machines for surface mount devices, different alignment tools, automatic paste machines, conveyer belts and several injection moulding machines. The production of PCBs and mechanical parts are outsourced. All the other production steps are done by Kuebler.

There is a worldwide distributors sales network. Kuebler is represented in over 45 countries. The turnover is split as follows: 63% electromechanical counters, 23% electronic counters, 14% encoders. About 55% of the products have been exported, worldwide.

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

Market Overview for All Products

Kuebler market share before AE (estimation):

	Electromechanical counters	Electronic counters	Encoders
Germany	20 %	10 %	5 %
Export worldwide	5 %	2 %	<1 %
General market trend	Stagnation	Stagnation	Growth

Percentage of product related Kuebler turnover:

	Electromechanic counters	Electronic counters	Encoders
1996	63 %	23 %	14 %
1998	63%	18.5%	18.5%
2001 without AE	55 %	20 %	25 %
2001 with AE	40 %	16 %	44 %

Although Kuebler are continuing to develop all of their products the company believes that their major growth will be in the encoder market. Thus they wished to concentrate their R & D effort in this sector.

Market Overview for Encoders

The company has a total market share of about 1% of the 1.5M standard encoders estimated to be sold annually in the EC. However the company's market share for custom tailored solutions is much higher. In 1996, 80% of the sales went to Germany, 19% to other EC-countries and 1% to overseas.

Technological Level of the Competitors

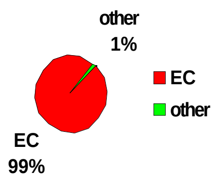
	Technological level	Definition
20% of competitors	High	ASIC, Microsystem, full custom, ...
60% of competitors (+ Kuebler)	Medium	SMT, photodiode-arrays, microcontroller
20% of competitors	Low	Discrete components

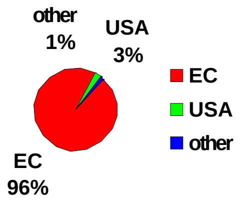
Kuebler decided that in order to improve their competitive position from where 60% of their competitors also were they needed a new product. This would need to be produced at a lower price and be more suitable for mass production. The new product would also need better performance in terms of high temperature, shock, vibration and EMC (according to the CE-conformity standard, but without an expensive metal housing). And it would need to have a faster time-to-market in custom (high-end price) encoder applications. By way of an example, there were approximately 70 types developed in 1998. New, more competitive markets, especially in the USA and Far East would then be open to them.

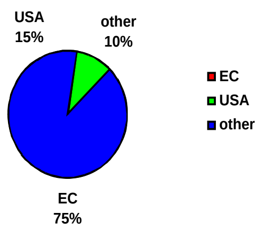
Provided that the new product meets these requirements the future sales projections indicated diagrammatically, should be achievable.

Sales in 1996 and 1998 without new products

Sales in 2001 with new products







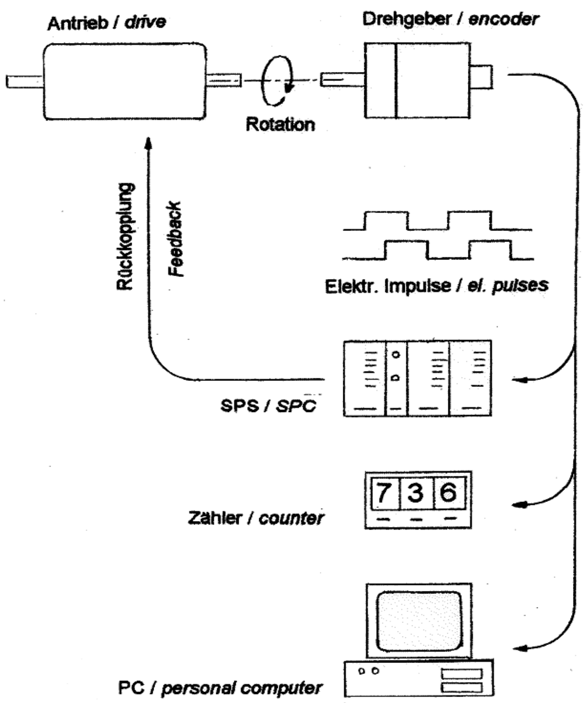
5. Product to be improved and its industrial sectors

Encoders are sensors used in motion sensing applications (e.g. robotics, electronic drives, machine-tool controls) where angular displacements and distances are measured and monitored by evaluation electronics (e.g. SPC).

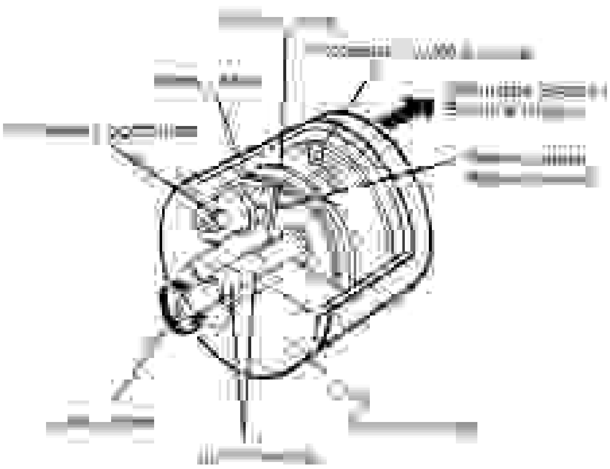
The company delivers encoders to a wide range of potential customers as they are: the robotic industry, the electronic drive industry, the machine-tool control industry, the Petro-chemical industry and the paper - and wood industries. Kuebler offers a special service to his customers and designs custom tailored solutions (e.g. explosion proof variants for the chemical industry and radiation proof variants for the medical industry).

An encoder is a transducer, which translates rotation of mechanical revolutions into proportional electronic pulses. The number of pulses, recorded by counters or microcontrollers that represent an angular displacement or a distance. This information is used to calculate the position in various instrumentation e.g. of a robot arm. The technology used at present is based on optoelectronic components, e.g. photodiodes. When the encoder shaft is turned by a drive the light of an LED is modulated by a scale (e.g. a structured chrome-on-glass disk). The modulated light is sensed by (e.g.) photodiodes and thereafter amplified and shaped to digital electronic output signals.

Figure 1, encoder as a system component



The resolution of the encoder (= pulses per revolution) is determined by transparent lines on a disk (= scale), refer to figures 2 and 3



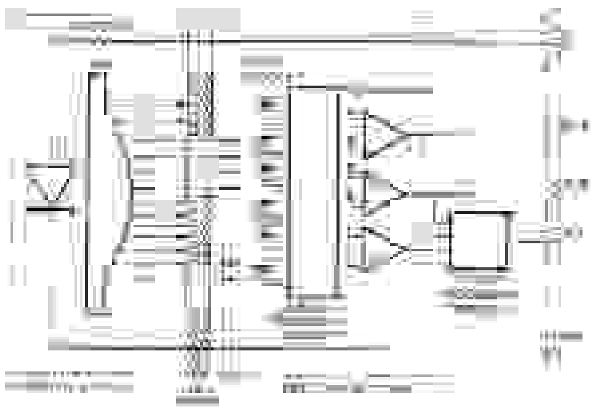


Figure 2, Encoder assembly principle **Figure 3, Encoder & sensor block diagram**

This technology of discrete optoelectronic parts on a PCB and a glass disk is too sensitive in a wide range of applications where high temperature (> 100°C), high shock resistance and high electro-magnetic immunity is needed. Furthermore it is too expensive for high volume applications (e.g. automotive industry) and for low cost markets (e.g. India, China) which require low cost products.

Whilst Kuebler design encoders for specific customer applications they all use the same components described below. Differences are on size and accuracy of the parts, output format and connection methods to the shaft.

In summary the existing product is expensive to produce and assemble, and also has some significant performance limitations. In addition it is large, which means it is unsuitable for some applications where there is limited space available.

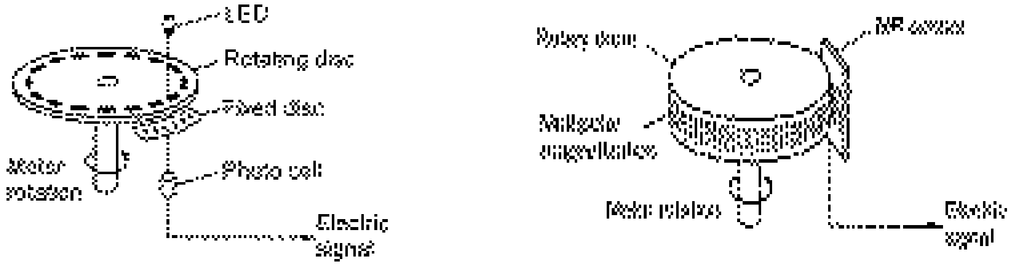
The list price for these products varies from 150-250ECU/item.

6. Description of the technical product improvements

The objective of this AE was to reduce the cost of the existing encoder products, and remove the environmental limitations concerning poor performance at high temperature, and sensitivity to shock, vibration, EMC, water and dust. The final solution was also smaller (30% of the original size), which makes it suitable for applications where space is an issue.

This was achieved by developing a microfabricated sensor array, a magnetic multi-pole ring and a mixed signal ASIC to interrogate the sensor array. These 3 components replaced the photo diode array, signal-conditioning electronics using SMT, two glass disks used as optical scales and a light source.

Figure 4, comparison between the basic components of an optical & magnetic encoder

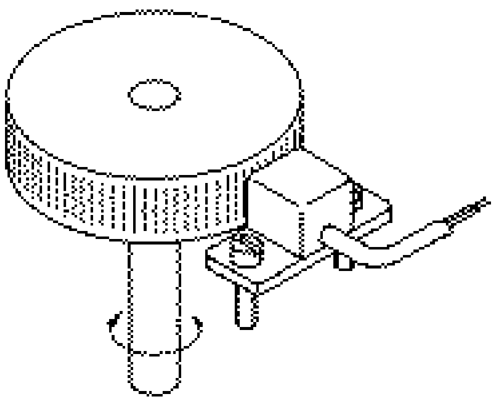


The sensor array is a magneto resistive bridge array which is sensitive to magnetic fields and is formed on silicon. The overall size of the array is approximately $4.5mm^2$. This was developed as part of this AE.

The magnetic multi-pole ring is a standard bought in item. The only development work needed was polarising the ring to give the required system resolution. This polarisation method was developed during the AE. Once in production other more cost effective methods may be investigated. The distance between the multi-pole ring and the sensor is 0.1 to 0.5mm.

The third part, the electronics to interrogate the sensor and produce a digital output was developed in this AE as a mixed signal ASIC. This ASIC, with a silicon chip area of 2mm x 2 mm will be mounted on a common substrate with the sensor array. Thus the final system solution comprises two parts, the multipole ring and the sensor plus ASIC.

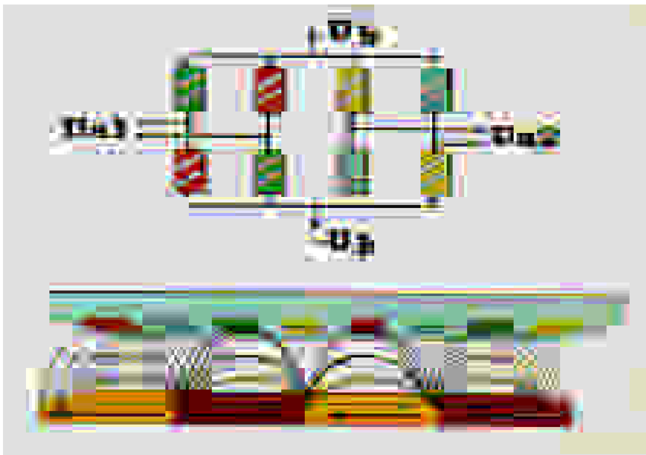
The complete system is shown schematically below:



The resolution of the encoder i.e. pulses per revolution is determined by the number of poles on the magnetic multi-pole ring. The magneto sensitive sensor is modulated by the multi-pole ring and generates sinusoidal signals. Since the resolution of this magnetic system is up to 50 times lower that the optical system, an additional interpolator is required within the ASIC in order to make the performance of the final device comparable.

Figure 5, Principle of a Two Channel magneto resistive sensor system:

from bottom to top:
- ***magnetic multipole scale***
- ***sensor***
- ***two bridge circuitries***

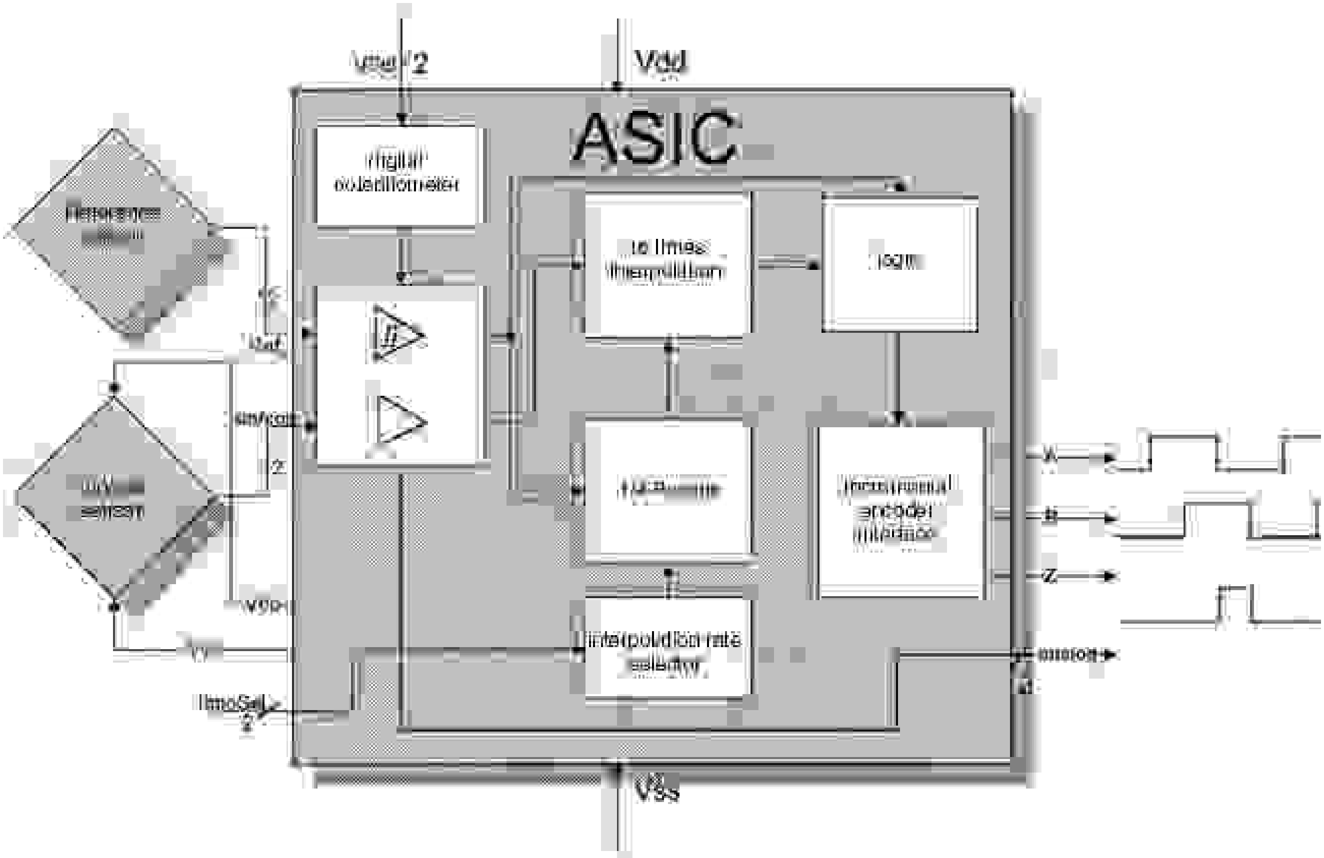


The ASIC performs the following functions:

Amplification of the input signal
Interpolation of the signal
Logic
Digital output

The signal and the amplification of these signals is insensitive to temperature, shock, vibration and EMC. Thus the complete system overcomes the limitations of the current encoder products. The ASIC comprises both analogue and digital signals, with scanning and output frequencies around 300 KHz. A schematic of the ASIC which is 2mm x 2mm and has around 64 gates plus the analogue functions is shown below:

Schematic of ASIC and Sensor



A summary of the specification of the new magnetic based encoder compared to the existing optical system is given below:

	Optical encoder based on Discrete parts	Magnetic encoder based on a Microsystem
typical temperature range	0° / +70°C	-55 / +125°C
Shock	< 100g	>> 100 g
Vibration	< 20 g	> 20 g
EMC	Sensitive (discrete elements)	Insensitive (monolithic)
sensitivity against dust, water	Yes	No
max. scanning & output frequency	300 kHz	> 300KHz
sensor chip size (3 channel)	15 mm^2 (6 discret photodiodes)	Approx. 4,5 mm^2 (monolithic)
sensor current consumption	Approx. 35 mA	Approx. 10 mA
Sensor output signal form	Triangle (not suitable for high interpolation)	Sinusoidal (can be interpolated to a higher resolution)
Sensor assembly & adjustment time	High (factor = 5)	Low (factor = 1)
Sensor costs	High (factor = 3)	Low (factor = 1)
Costs of the optical-/magnetic scale	High (factor = 2-10)	Low (factor = 1)
Encoder process throughput	High (factor = 3)	Low (factor = 1)
Process yield (whole encoder)	Low (95%)	High (99%)
Reliability (whole encoder)	Low	High
Size (whole encoder)	Big (100%)	Small (30%)
Design cycle time (whole encoder)	High (factor = 2)	Low (factor = 1)
Encoder costs	High (factor = 3)	Low (factor = 1)
Encoder installation time	High (factor = 3)	Low (factor = 1)

The overall cost of the new encoder compared to the optical encoder will typically be a factor of 2 lower, or potentially even less once production quantities are realised.

7. Choices and rationale for selected technologies, tools and methodologies

The first stage, before the AE started, involved Kuebler looking at all the physical principles possible for this application to do encoding on a shaft.

These were:

Optical - Already used
Magnetic
Capacitive
Inductive

Kuebler then looked at whether products were on the market for commercial use using these different technologies, whether their technical specification could be achieved, and the likely costs. The magnetic technology was chosen because:

- The technology is established at research level
- Target specification looked achievable
- Cost target looked possible - because it used semiconductor technology suitable for mass production

In comparison the capacitive and inductive methods both use older, conventional technologies, and are sensitive to EMC. The manufacturing costs with these older technologies are inherently higher when compared to the magnetic system. The reasons for this are that the individual components are precision parts that also have to be carefully assembled. Conversely, the magnetic system can be processed on a Silicon wafer, which minimises both manufacturing and assembly costs.

Having chosen the sensor technology it was necessary to establish which type of signal electronic would be chosen.

There were a number of choices available which would meet the technical requirements. The relative merits of these, in terms of cost and performance are summarised in the Table below:

Evaluation - Electronics Technology: Signal conditioning & A/D-conversion	**Cost/piece at medium quantity**	**Economic (starting costs) # K ECU**	**Technical**	**Development time**	**Design risks**	**Assess-ment rank: (1 = best solution)**
Discrete (about 100 parts) plus PCB and housing	high	70	bad EMC & temperature behavior	Short	low	4
1 x Analog ASIC 1 x Digital ASIC or FPGA	medium	200	good EMC & temperature behavior	Long	high	3
Integrated Circuit e.g. DSP = Digital Signal Processor	medium	90	medium EMC & temperature behavior	Medium	low	2
Mixed Signal ASIC	low	100 (using MPW)	good EMC & temperature behavior	Medium	med	1

Results of inquiries at the following potential ASIC subcontractors: CSEM (Switzerland)/ SOITEC, Thomson Components (France),IMO, IAM, Mazet (Germany)

It can be seen that for medium quantities the lowest cost option was a mixed signal ASIC. However before the feasibility study was carried out at the beginning of the AE, the starting costs were difficult to quantify. If these had been considerably higher for the mixed signal ASIC than the DSP solution then DSP would have been the preferred option. However, during the feasibility study it was found that if the MPW service were used the starting costs were comparable for the DSP and mixed signal ASIC solution. Thus the decision was taken to develop a mixed signal ASIC using MPW prototyping.

The final solution chosen was therefore a monolithic sensor using a 3 channel magnetic sensor on Silicon, together with a mixed signal ASIC. This solution provided:

- three channels which are necessary for speed, rotation direction and zero-position detection at low manufacturing cost
- good EMC and temperature behavior
- minimal the sensor volume
- the required system accuracy and resolution
- automatic channel-to-channel deviation
- the option that the ASIC could be tailor made for a suitable magnetic scale
- the possibility to integrate the signal conditioning and a error-correction circuitry into the ASIC

<u>Design Tools:</u>

It was decided to design the magneto resistive bridge array using ”Autosketch” because of its ease of use in conjunction with magneto resistive sensor structures. After the design procedure the results are translated into suitable semiconductor information.

The magneto resistive bridge array was fabricated using thin film technology, which is a common technology for conjunction with magneto resistive components. In addition, it offers the choice to incorporate EMC-compatible structures to avoid disturbances.

The evaluation electronics (= an amplifier, interpolation circuitry, schmitt-trigger and an output driver) was integrated into a mixed signal ASIC, based on a Alcatel Mietec 0,7µ CMOS process. Both components, the sensor and the ASIC, were mounted on a PCB together with some optional discrete parts, such as a connector, EMC-protection circuitry and a voltage regulator and covered by a sealing compound. This formed a complete Microsystem.

The component will be tested by automatic probes at chip level, using the test programme generated by the subcontractor. At the system level the whole system including sensor, the signal condition electronics and magnetic scale will be tested under different climatic and electronic conditions such as temperature, rotation speed, supply voltage, output current, mechanical stress.

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

Company's expertise prior to the AE

The company has expertise in the design of optoelectronically based encoders, electronic and electromechanic counters. In the field of electronics there was know how in analogue, digital, optoelectronic sensors and LED/LCD-display design. There was also experience in microcontroller programming, CAD-based PCB layout (PCAD) and surface mount technology.

In the field of mechanics there was expertise in CAD-based mechanical construction (Mega-CAD), tool-design for injection molding machines and optical scale design.

Expertise of the staff that participated in the AE:

Function during AE	Studies	Title	Special knowledge
Project manager	Electronics	Engineer	Managerial skills, patent investigation, encoder system design, general electronic design, opto-electronic sensor design, µC-software development
Project team member Mechanics	Mechanics	Engineer	CAD-based mechanical construction, bearing & sealing technics, manufacturing technologies for mechanical parts (e.g. laser cutting, etching)
Project team member Electronics	Electronics	Technician	General electronic design, responsible for final electronic circuit design, first sample assembly & tests and test evaluation
Project team member Marketing	Business	Graduate in business management	Market survey

All involvement was from the R & D group plus one person from sales and marketing.

9. Workplan and rationale

Kuebler had overall project responsibility for the AE, and had one sub contractor, IMO plus the TTN to assist them through the project. The foundry, who supplied the ASIC were chosen part way though the project and were sub contracted through IMO.

Originally it was planned that the electronics would be a software solution using DSP. However, once the specification was available it was clear that a far more cost-effective solution for mass production would be a mixed signal ASIC. When looking at the development costs and timescales with the sub contractor and the TTN, Kuebler determined that the ASIC solution could be achieved within the cost and timescales allowed for the project.

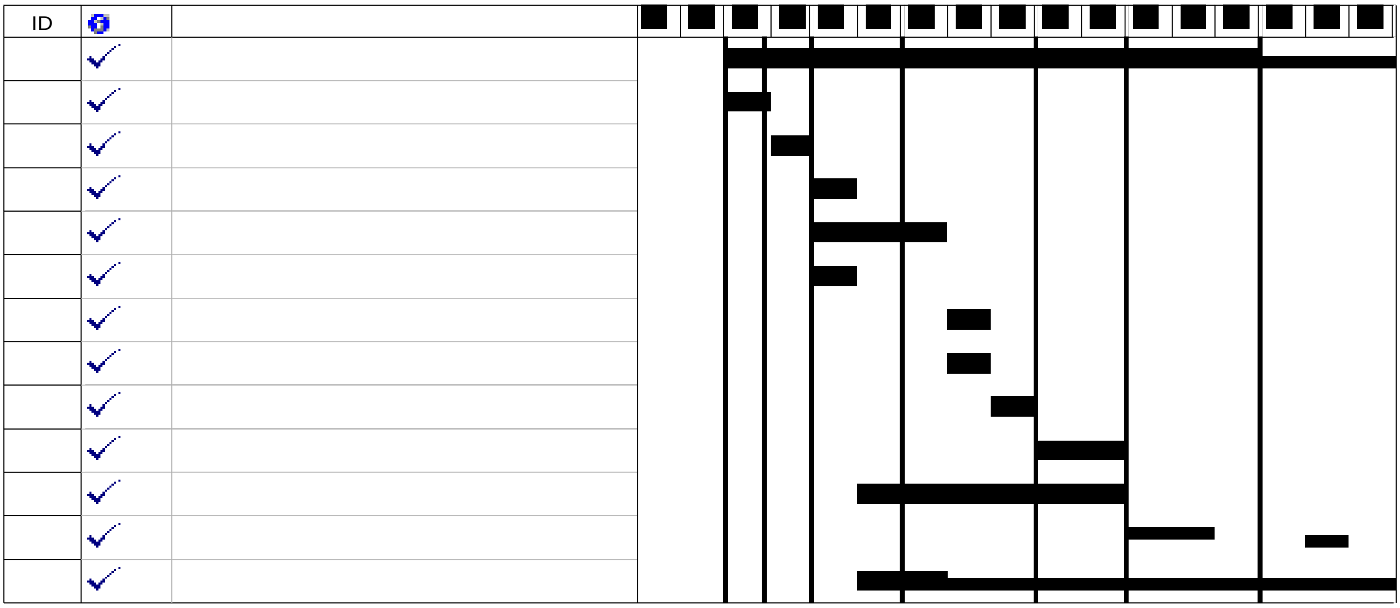
The project was originally planned to take 12 months but was actually delayed by 3 months due to the ASIC being produced using the MPW service from a foundry. Whilst this in itself would not have caused a 3 month slip, small errors on the ASIC meant that 2 iterations were required with a 3 month delay between each run. These iterations resulted in the overall 3 month delay. There was however no increase in cost.

It must also be noted that the cost of this AE was significantly lower than for comparable Microsystems, where both a microfabricated sensor and a mixed signal ASIC are developed. This is because the sub contractor part funded their work since they were keen to demonstrate that their sensor system could be developed in to a commercial device. Also the low cost development route of using the MPW service offered by some foundries was chosen for the ASIC.

The TTN was involved in helping to formulate the project plan and establishing that an ASIC developed using the MPW service was feasible for this application. Each month the TTN ensured that suitable progress was being made against the plan.

Workplan showing actual and planned

Top Line – Planned timescales **Bottom Line – Actual**



Task	Milestone (total costs for this milestone / time of subcontractor)	Work carried out, interactions and information exchange
1	Technical management (8.100,- ECU / 7 days)	***Proposer:*** - FUSE specific managerial work (e.g.cost statements) - Workflow organisation & information distribution within the AE- team at Kuebler - Workflow organisation & information distribution from/to third parties - Checking the work plan (milestones) - patent investigations - Organising third party visits & meetings (e.g. with chip packaging & magnet manufacturers ***)*** ***Proposer & Subcontractor*** - working out the contract with subcontractor
2	Training (1.595,- ECU / 3 days)	***Proposer*** - Organising in house & external training ***Proposer & Subcontractor*** - Two days training at the subcontractor with the following topics: - overview about the latest technologies - sensor chip specification & testing & packaging - risk and cost estimation - project time calculation - magnetic scale specification, testing and manufacturing - cooperation procedures with third parties
3	Specifications (12.000,- ECU / 4 days)	***Proposer*** - Target specifications of the whole encoder - Coarse specifications of the sensor & ASIC ***Proposer & Subcontractor*** - Detailed specifications of the sensor & ASIC - Quality assurance specifications
4	Selection of a evaluation circuitry	***Proposer*** - A DSP (Digital-Signal-Processor) was proposed as evaluation circuitry as a compromise because of high starting costs for an

	(3.000,- ECU / 4 days)	mixed signal ASIC ***Subcontractor*** - The subcontractor pointed out, that thanks to a MPW (Multi-Project-Wafer) it is possible to cut the starting costs for a mixed Signal ASIC essentially ***Proposer & Subcontractor*** - Recalculation of evaluation circuitry - Decision to replace the DSP by an ASIC at about the same costs - ASIC specifications
5	Sensor design & layout (11.000,- ECU / 4 days)	***Subcontractor*** - Sensor design & layout with ”Autosketch” & ”AutoCAD” - Design information passed to Proposer ***Proposer*** - Design assistance ***Proposer & Subcontractor*** - Discussions about the most important design steps and their relevance for the specifications
6	Magnetic scale layout (2.000,- ECU / 2 days)	***Subcontractor*** - Elementary information passed to the Proposer to enable him to lead negotiations with third parties ***Proposer*** - Market survey on the most important magnet manufacturers - Negotiations with third parties (magnet manufacturers)
7	Sensor prototyping (25.600,- ECU / 2 days)	***Subcontractor*** - Sensor prototyping - Manufacturing process information passed to Proposer ***Proposer*** - Visiting the subcontractors’ in house production line for sensors
8	Magnetic scale prototyping (700,- ECU / 2 days)	***Proposer*** - Orders for different magnetic samples - Tests of different magnetic samples (accuracy, costs, quality) ***Subcontractor*** - Technical assistance
9	Sensor & scale pretesting (2.800,- ECU / 0 days)	***Proposer*** - Tests: climatic chamber, accuracy, alignment errors, temperature dependency - Preamplifier optimisation (e.g. temperature compensation)
10	Sensor optimisation (0,- ECU / 0 days)	Was not required! Sensor was O.K. This was a part of the contingency plan.
11	Preparing test tools (1.300,- ECU / 0 days)	***Proposer*** - PC controled drive system - PC based evaluation board for sensor signal evaluation - x,y,z-positioning table for accurate sensor to magnet positioning - several mechanical devices (a magnet holder, shaft & bearing) - Electronic hardware (e.g. amplifier circuits)
12	Encoder system test (2.500,- ECU / 0 days)	***Proposer*** - Since the ASIC was not available according to the projected time table, the sensor system (= sensor, ASIC, magnet) specifications had to be verified by using a circuitry similar to the planned ASIC. - The test was successful
13	Ev. Circuitry design (ASIC) (23.800,- ECU / 4 days)	***Subcontractor*** - Mathematical error simulation. Results passed to proposer - ASIC design - Manufacturing process information passed to Proposer - Tests with the first samples ***Proposer*** - Verification of the simulation & first sample test results ***Third party*** - ASIC prototyping (MIETEC)

Summary of effort

	FU (Days)	Sub Contractor (Days)	Total cost (K ECU)
Total	**92 ACTUAL** **78 PLANNED**	**32 ACTUAL** **32 PLANNED**	**94.4 ACTUAL** **91 PLANNED**

Task	Milestone	Explanations to the deviations:
1	Technical management	The lengthened managerial work results from task 13 – ASIC not finished
10	Sensor optimisation	Was not required! Sensor was O.K. This was a part of the contingency plan.
12	Encoder system test	Since the ASIC (task 13) was not finished, it had to be looked for an ASIC replacement circuitry.
13	Ev. circuitry design (ASIC)	There was a several months delay. The subcontractor stated two design errors when verifying the first samples. He had to wait three months for the next MPW run (MPW = multi project wafer)

10. Subcontractor information

Kuebler chose their sub contractor based on their specific requirements for the sensor, since this is still a new sensor technology only offered by specialists. The sensor technology chosen for this AE was magneto resistive (MR) sensors on Silicon. Kuebler investigated who was offering this technology in Europe, and found only 2 potential sub contractors, IMO and Philips. Whilst both stated that they could design and manufacture these devices, neither could offer a standard product. Keubler had initial discussions with both and concluded that Philips were not keen to undertake the job, were not flexible enough to work with SMEs, and were not keen to produce small quantities. Conversely IMO were very keen to develop this product, to the extent that they were prepared to part fund their work. They were also prepared to start the work without a contract. This meant that there was shared risk between the FU and the sub contractor.

Once Kuebler had chosen IMO as the sub contractor the TTN helped them prepare a contract. The contract that they had with IMO was fixed cost for the sensor and the ASIC, and the FU owned all the IPR. This contract was not finalised until 3 months on in the project when it had been established that a mixed signal ASIC would be produced. IMO also gave 2 options for foundries offering MPW which IMO could work with, and who offered the necessary technical solution. MIETEC was therefore chosen on cost grounds, and IMO had their own contract with MIETEC to produce prototype ASICs to IMOs design.

Subcontractor 1

Name: IMO Institute für Mikrostrukturtechnologie und Optoelektronik,
Im Amtmann 6, D-35578 Wetzlar, Germany, Tel +6441 97 88 15, Fax +6441 97 88 17

Size: IMO has about 25 employees

Business

IMO has three main business areas:

Firstly there is a consulting activity about customised miniaturised sensor systems, particularly when considering the size, the costs or a technology comparison.

Secondly IMO offers the option of sensor and electronic circuitry developments. The central know how are Magneto Resistive (MR) sensor chips, sensor ambient microelectronics and system engineering. IMO offers the whole development process of customized sensor chips from design and simulation to manufacturing and testing. Ambient electronics can be designed by IMO but is manufactured by a specialised semiconductor manufacturer.

Last but not least IMO is able to produce small and medium quantities of the above mentioned sensors or systems.

Relevant Expertise & Experience

IMO is experienced on the field of integrated circuits design such as ASICs, FPGAs and Microsystems. There is an excellent knowledge about magneto resistive sensor design. The institute offers the whole range of system integration, such as electronic circuit design, electromechanical interface technique and final system testing. Even an in-house production of small quantities is possible.

Services provided

In this AE IMO offered their experience in MR sensor Specification, Design and Production. Their specialities are sensor designs with a very low sensitivity to stray signals. They assisted in evaluating the electronics for the sensor, in specifying and designing it and procuring it from a foundry. They offered their dedicated equipment to Kuebler to test and evaluate the first samples. Furthermore, they provided a magnetic scale counterpart needed for the first system test. Their connections with third parties like services for magnetic scale sample production, magnetic pattern programming and high volume sensor production were also used when developing the production programme.

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

There were a number of barriers perceived at the start of the AE, which had to be overcome by Keubler if they were going to successfully develop the new product.

Firstly Kuebler faced the pschological barrier associated with moving from a 'known traditional' technology in to a new technology where the personnel in development, production and sales and marketing have no knowledge.

Their lack of technical knowledge also meant that they were unable to estimate the cost or timescales of the development project, and were hence unable to calculate a return on investment (ROI). In addition, they were unable to assess the potential of product improvements that could be achieved using the new technology.

There was also a burrier concerning the investment in production line and test equipment which would be required. Again it was impossible to allocate investment in this area without knowing the benefits of introducing the new technology.

And finally, Keubler had not known how to prepare a suitable contract with sub contractors which would include such aspects as cost and time penalty clauses.

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

Firstly Kuebler undertook a market survey on the latest technologies. These included work published by institutes, universities and technology transfer nodes, plus companies who have introduced the new technologies. Meetings and information exchanges were organised with those who appeared to be most advanced, and from these Kuebler were able to fully assess where the different technologies were.

From this, Kuebler generated a look up table with all the relevant information (cost, size, time to market, technical advantages) for the existing and all alternative technologies. This was used as a discussion document with all the relevant departments (design, production, sales and marketing), plus the top-level management. Collectively they then agreed to pursue this new technology, having also established that a suitable ROI could be achieved.

Kuebler then chose the most suitable sub contractor to assist them in this AE. Their choice was based on the sub contractors technical knowledge, training facilities, cost, commitment to the project and availability of design tools and test equipment.

To prepare a suitable contract, Kuebler sought help from the TTN, and together they prepared a suitable contract, which included penalty clauses.

The lack of production and test equipment was overcome by outsourcing this work.

13. Knowledge and experience acquired

Knowledge and experience acquired	Investment made to acquire each skill
- Technical management, - Workflow organisation & information distribution from/to third parties, - Patent investigations, - Organising in house & external training	- learning while conducting the AE - result of information flow from subcontractors to the FU – self learning
- Working out the contract with subcontractor	- learning while conducting the AE - result of information flow from subcontractors and third parties to the FU
- overview about the latest technologies - sensor chip specification & testing & packaging - risk and cost estimation - project time calculation - magnetic scale specification, - testing and manufacturing	- formal training (Two days) - learning while conducting the AE - result of information flow from subcontractors to the FU – self learning (technical literature)
Cost reduction choices (e.g. MPW = multi project wafer)	- result of information flow from subcontractors to the FU
- More knowledge about the magnetic sensor market (e.g. potential subcontractors for sensors and magnets) - technological transfer nodes - More transparency about other sensor choices for new products (optelectronic, magnetic, inductive, capacitive)	- learning while conducting the AE - result of information flow from subcontractors to the FU – self learning - meetings with technological transfer nodes (e.g. universities)
- Magnetic scale prototyping - Sensor prototyping - Test procedures - Amplifier circuitry layout and temperature compensation - Mathematical error simulation	- learning while conducting the AE - result of information flow from subcontractors to the FU – self learning (e.g. brochures of magnet manufacturers) - visiting fairs and seminars and manufacturers

To establish the new technology at Kuebler a knowledge transfer was required on the following fields:

- overview about the latest magnetic sensor technologies
- chip design specification
- sensor & system simulation
- monolithic sensor chip design & test procedures
- high resolution magnetic sensor development
- sensor manufacturing process
- choices of cost reduction during a chip design & manufacturing process especially for small and medium sized companies
- magnetic scale design and production
- high temperature chip packaging technologies
- address list of potential third party subcontractors (e.g. test, packaging, design aid)

14. Lessons learnt

Lessons	Remarks
Refining the definition and features of the sensor product due to a better understanding of the technology as the AE progresses	The technical potential of the new sensor technology was found to be much higher then rated at the beginning of the AE. Therefore a more sophisticated product was possible than first planned.
The need to change the specification during the AE due to changed targets	A DSP (Digital-Signal-Processor) was proposed by the Proposer as evaluation circuitry as a compromise because of high starting costs for a mixed signal ASIC. But the subcontractor pointed out, that thanks to a MPW (Multi-Project-Wafer) it is possible to cut the starting costs for a mixed signal ASIC essentially.
Subcontractors delayed	There was a several months delay. The subcontractor stated two ASIC design errors when verifying the first samples. He had to wait over three months for the next MPW run (MPW = multi project wafer). It is advisable to invest more time to look for a suitable foundry offering wafer runs within a month!
The subcontractor has assisted the FU in an area where they had not planned	It is difficult to overlook all the necessary special test equipment. Finally we find it time- and money saving to use the test equipment of the third parties.
Subcontractors not delivering according to specification	Important contract parts: If the technical or quality specifications are not observed by the subcontractor and therefore a new product is not possible on the basis of the new sensor all the starting costs have to be carried by the subcontractor. This is because the sub contractor stated they could deliver a product to the specification at the outset of the AE. If the time schedule is not observed, there should be a cost reduction per month incurred by the Proposer.

15. Resulting product, its industrialisation and internal replication

The prototype which has been tested met all of the performance criteria, except for the maximum scanning and output frequency. The final product will have a maximum of >300KHz, but not as high as the 1MHz in the original specification. However, this does not limit the potential application areas, and still exceeds the existing system. Kuebler are now at month 7 through the process of productionising the product, in accordance with the plan given.

Project plan – Industrialising the new product

Task	Months	1	2	3	4	5	6	7	8	9
1	Technical management	//////	//////	//////	//////	//////	//////	//////	//////	//////
2	ASIC-test	//////								
3	Discussions with key customers	//////								
4	Encoder specifications		//////							
5	Selection of suitable third parties (magnet manufacturer & chip packaging company)	//////								
6	Encoder design & layout			//////						
7	Magnetic scale design & layout			//////						
8	Magnetic scale test (with sensor) & prototype manufacturing				//////	//////	//////			
10	Encoder system-test & prototype manufacturing						//////	//////	//////	
11	Preparing data sheets and docu-mentation for the new encoder type							//////	//////	
12	Training of sales department and representatives								//////	//////
13	Encoder series manufacturing start									X

The total cost of industrialising and marketing the final product is estimated at 100 KECU. Approximately 60% of this will be for production items (mouldings, tooling etc).

There is also a good relationship between the FU and the subcontractor and hence the FU maintains access to the subcontractor's facilities such as magneto resistive sensor test equipment, simulation and design tools.

Furthermore Kuebler have found new third parties in the fields of accurate microsystem and high volume chip packaging, magnetic field simulation (static & dynamic) by finite element method and several magnet manufacturers with different outstanding manufacturing and precise magnetisation techniques.

Having more than one co-operation partner is important, since it is difficult to cover all the different customers' needs by only one technology process and the know how is kept within our company because there is no 100% technology transfer to only one subcontractor.

During the AE some potential customers, covering different sensor application fields, have been visited and selected as "key customers". With those key customers a detailed encoder specification will be worked out at the start of the industrialising process.

Especially the chip packaging knowledge obtained during the AE will also be used to optimize price, size and reliability at the electronic counters.

Having learnt about the sensor technology during the AE, believe that this sensor technology could potentially replace the complete range of optical encoders that Kuebler make, at a lower price. In addition new features may be possible. Kuebler will now look at each of their other encoders in turn to see how they can be replaced with this technology. They plan to start this activity about 12 months after this AE finished (3 months after the first one is in production).

16. Economic impact and improvement in competitive position

Compared with the optoelectronic based encoders, the new product has a higher temperature range of up to +125°C, is more shock and vibration resistant, is insensitive to water and dust, and less sensitive to EMC disturbances.

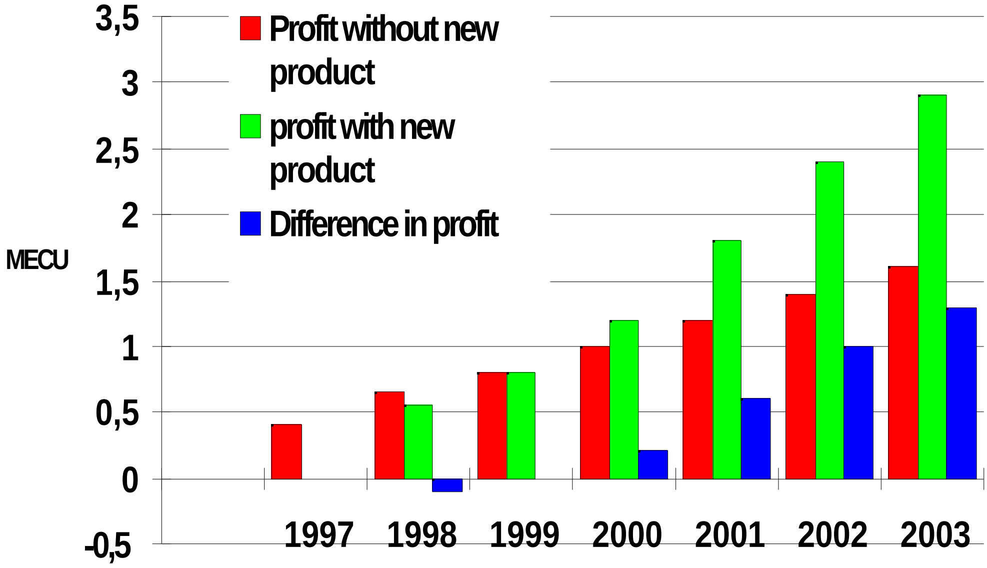
The sales forecast for the year 2002 is about 4.3 MECU without the new magnetic technology and about 6.2 MECU with the new products based on the magnetic technology. Also due to less alignment and assembly requirements a lower price can be realized and therefore the products become more competitive for mass applications especially on the USA and Far East market.

Sales Forcast (MECU)

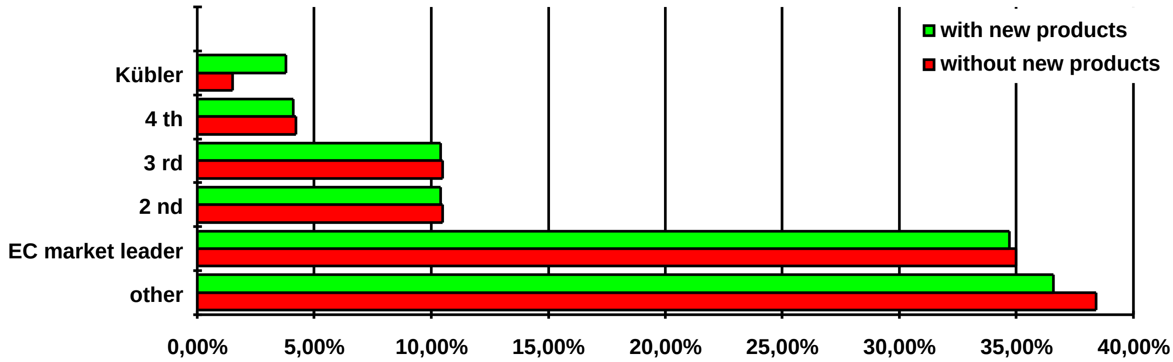
Existing product without new product	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
earnings	1,0	1,4	1,9	2,4	3,0	3,6	4,3	5,0
costs	0,65	1,0	1,25	1,6	2,0	2,4	2,9	3,4
profit	0,35	0,4	0,65	0,8	1,0	1,2	1,4	1,6
With new product			**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
earnings			1,9	2,5	3,6	4,9	6,2	7,2
costs			1,35	1,7	2,4	3,1	3,8	4,3
profit			0,55	0,8	1,2	1,8	2,4	2,9
Difference in profit			- 0,1	0,0	+0,2	+0,6	+1,0	+1,3

The payback period, assuming a total development cost of 200K ECU, including the 94 K ECU for the AE, will be 1 year after completion. For the AE alone, this reduces to 6 months.

The ROI will be at least 30 times the AE investment assuming a 4 year life cycle.



Estimated EC Market Shares in 2001:



17) Target audience for dissemination throughout Europe

This AE described how Kuebler, an SME has developed a Microsystem including a magnetic sensor and mixed signal ASIC for encoder applications. The Microsystem replaces their existing optical system, which is large and expensive to produce and assemble. In addition it is sensitive to high temperature, EMC, shock and vibration, dust and water.

Kuebler has demonstrated that a technology, which has been proven in the research environment but is not yet available as a commercial unit, can be turned in to a marketable product. Kuebler have also shown that by selecting a sub contractor who is keen to help bring their concept to market, the development costs can be kept to a minimum.

The result of Best Practice in Project Planning, choice of technology and sub contractor to assist with technology transfer is a complete micro system developed at a very competitive price, with a FU now able to extend this technology in to their range of products.

Microsystem development projects always contain some technical risk. This has been minimised in this project by getting the sub contractor to back the project from their own budget. The only problem which resulted was a delay in obtaining the ASIC because the low cost prototype-manufacturing route of MPW was chosen.

Companies that are likely to benefit from this AE are those interested in developing a Microsystem using a microfabricated sensor. Prototype sensors must be proven, and may be available from either research organisations or commercial companies. It is however likely that the sensor would not have been fully proven for the particular application of interest to the FU, and would need some further system development. The drive and detection electronics do not have to be realised in a mixed signal ASIC for replication exercises. However, most benefit would be gained by other FUs if they could learn by the experiences of developing a low cost ASIC for their sensor application.

In summary, this AE demonstrates:

- a better price to function relation makes products attractive to new customers and even to new markets outside Europe.
- the new sensor technology makes the encoders suitable for new application fields.
- even with a conservative sales forecast the payback is short at 6 months, and the ROI high at 30 times the AE investment.
- Good cooperation with sub contractors, has demonstrated how high technology know how can be transferred very quickly into the company, thus reducing time to market.
- a higher technology level is now the platform for the company's future.

The companies likely to replicate this AE are likely to invest in technology development, and be prepared to take a risk. Their internal expertise and project management skills would need to be fairly advanced, particularly in the technology area in which the microsystem is to be developed. The size of the company is not critical, although it is likely that the necessary skills would be available in a company with less than 20 employees.

The main reason for developing a new product in any replication exercise should be to realise a low cost system, with improved performance and manufacturing process when compared to the existing product.

The industrial sector most likely to benefit from the AE is Control and Instrumentation. However any industrial sector interested in sensors or microsystem development would also benefit. These include robotics, control, medical equipment and the petro-chemical industry.