FUSE AE 2119

Chipcard reader for electronic cash:
Mixed signal ASIC opens new markets for a small company

Demonstrator Document

Abstract

Cards & Devices GmbH, Seebach is a small enterprise with 5 employees founded in 1994. It's main business is the development, manufacturing and sale of smart-card products. The company operates in the business field of measuring instruments (3320), especially in the field of hand-held counters (33206430). The product spectrum of the company includes smart cards according to ISO 7816, smart card readers and interface devices as OEM. Most of the products are sold on the German market but also to other European countries.

One of the main products and the object of this AE is the micro-reader called "Smart-Cover" that was introduced into the market in 1995, e.g. as a reader for electronic purses or other information stored in smart cards. The product can be used for checking of different kinds of smart cards, such as telephone cards, electronic purses etc.

The technical solution was based on standard components and IC's (controller 80C31, EEPROM, LCD driver, Logic IC's) mounted on a multi-layer PCB. The company has the necessary knowledge and the development tools to realise products at this technology level itself. However, the realisation of this functionality with standard components is expensive and results in a relative big product with limited reliability. The company needed to reduce costs and improve reliability to compete with the many suppliers in this market.

The objective of the AE was therefore to introduce mixed signal ASIC know-how to Cards and Devices and to improve in this way the existing product. The company learned to manage such projects and to design and simulate mixed signal ASICs. The specialists got best practice knowledge in the application of embedded microcontroller cores and test strategies for complex systems with ASICs.
The main management and know-how barriers could be overcome by a very efficient know-how transfer process and a close co-operation with the subcontractor. This can be also seen in the schedule:

The project was started in June 1996 and was finished as planned after 10 months in March 1997.

The total costs up to the prototype stage were 129 k€. With the estimated sales figures a payback period of about 2 years and a ROI of about 350% over the expected product life time of 5 years.

Keywords

Mixed signal ASIC, Embedded Cores, MARC4 Controller Core, Mentor graphics, Smart card products, Electronic purses, Small company

Signature

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1. Company name and address

Cards & Devices Chipkartenlösungen GmbH
Neue Straße 67
D-99846 Seebach

2. Company size

Cards & Devices Seebach was founded in 1994 having an annual turnover of about 900 k€. It is an independent company owned by the manager Mr. Klemm.

The staff consists of 5 employees, two of them are engineers. In the application Experiment, the manager of the company (technical management & development tasks) and one design engineer (development tasks) were involved.

3. Company business description

Cards und Devices main business belongs to the industry sector "Instruments and Appliances for measuring, checking and testing. The company develops, produces and sells smart card products, especially smart cards according to ISO 7816, smart card readers and interfaces (OEM) as well as hand-held-readers for smart cards.

In addition the company develops also the software to be implemented in these devices. Those readers and interface devices are produced according to OEM specifications and have to be customised. This requires:

- modification of PCB layout
- integration into the customers existing systems, including the adaptation to other kinds of interfaces or the connection to other host systems
- special requirements of technical parameters such as power consumption, working temperature and dimensions
- user specific software

As an universal standard product suited for the use of electronic purses in a wide range of business sectors (POS-Terminals, vending machines, ticket machines, etc) the device " ec-Interface 046EHD01" was developed. Some of the products are:

a) smart cards
   - rechargeable smart cards for public transportation systems and parking meters and especially smart cards for payment systems
   - smart cards as a mean of identification for access control or data collection systems
b) smart card readers
   - smart card readers for initialising, personalising and testing
   - smart card readers as a charging station for stored value cards
c) interface devices (OEM)
   - customised interface devices
   - interface devices for the German electronic purse, called "Geldkarte" of the German banking Central Credit Association (ZKA)
d) hand held readers
   - hand-held-readers for the German health insurance card ("Versichertenkarte")
   - mobile data collection devices for fire departments

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

Because Cards and Devices is a small company, marketing activities were restricted up to now mainly to the national market. As a consequence, almost all products were sold in Germany. However, some of our devices are used in other European countries (e.g. Hungary, Spain, Norway) due to the OEM-Business, too.

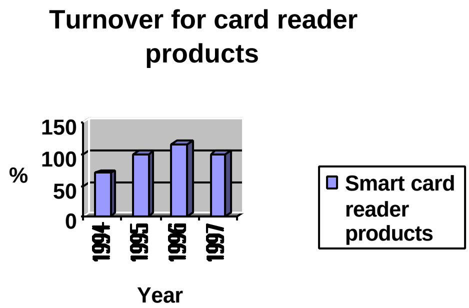
Miniature smart card readers (Balance Reader) are products, that have been on the market for a few years. A need for those readers was created and is created with the introduction of electronic purses. The German electronic purse, called GeldKarte, of the German Banking system is one of the world's biggest projects in the area of electronic cash, because it holds between 30 and 40 million cards. German banks estimate a need of about 50 % of this number to be the market for "pocket readers".

The overall market for smart card products is growing very fast. Nearly every day a new systems are put into operation. We estimate the overall market size in Germany to be in the range of 50 million € per year with positive tendency, about 15% of it in East Germany, our main distributing area. Here our market shares were as follows:

- smart card interfaces for parking meters : about 10 %
- smart card interfaces for the GeldKarte : about 15 % (different kinds of applications)
- smart cards for public traffic applications : about 20 %

In the last years we started to introduce our products also to West German customers successfully. Typical customers are banks, telecom or insurance companies. But also operating companies of parking systems or the public transport are buying our products. In addition, the system is sold as OEM product to manufacturers of more complex systems for banking, access control or parking.

At least 10 registered producers of "pocket readers" are currently offering smart card readers on the German market. However, it is dominated by big companies, for instance PANASONIC, TOSHIBA, HITACHI. The problem for our company was, that competing card reader products were based on advanced microelectronic technologies, i.e. ASICs were used. Our old solution was equipped with discrete analogue and digital components and a microcontroller as well. They were too big and too expensive in the manufacturing. Therefore, the turnover did not increase anymore, despite the absolute growing of the market, as can be seen in the table (Basis 1995: 100%).



As already stated, the company has had a total turnover of about 900 k€ per year. The share of our reader systems to be improved within this project is in the range of 30 %. It was our intention to extend the share of the reader products in the company's total business, because the pure smart card market is dominated by Far East competitors with low prices and therefore very complicated for us.

It was necessary to reduce the manufacturing costs and to increase the reliability and functionality of the product. The objective was to gain at least a significant regional market share for this product. The only way to meet this objective was the introduction of new microelectronic technologies to the company's business. This clearly demonstrates the importance of the Application Experiment for our business.

5. Product to be improved and its industrial sector

The existing product "Smart-Cover" is a chipcard reader for microcontroller based chip cards according to ISO 7816. The product is shown in the following picture.

Fig 1. "Smart-Cover"

The access to the information which is stored in this smart cards must be guaranteed for the user at any time. All information is available without the input of a Personal Identification Number (PIN). For instance, the following information must be read out depending on the application:

- current balance of the "electronic purse"
- transfer data (when, how much...)
- data of card owner like: name, card number, bank name

By introducing the card in the card reader the contact area on the card is connected to the contact area of the reading unit. After successful connection the data of the card will be read out and processed by the reader, i.e. the data are checked, coded and decoded, respectively. Finally, the information is displayed on the LCD.

The old product "Smart Cover" (Figure 2) is realised by the use of standard components, i.e. microcontroller, EEPROM and standard IC's which are assembled on a PCB.

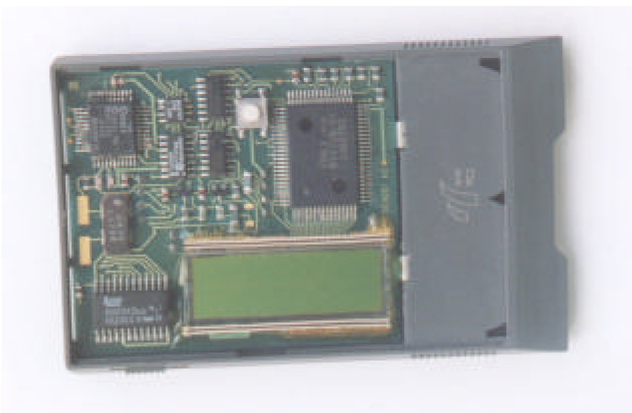


Figure 2: PCB "Smart Cover"

The realisation with standard components had a variety of technical and economical disadvantages. Mainly, those problems were the results of the use of standard components: To meet the functional requirements several Standard-ICs (Controller 80C154, external EEPROM as program storage, LCD-Driver, Logic-ICs, quartz oscillators) were used. The high number of components and the related manufacturing costs (complicated construction and housing, high PCB assembly and testing costs) made the product expensive and more and more uncompetitive. The block diagram of the old product is shown in Figure 3:

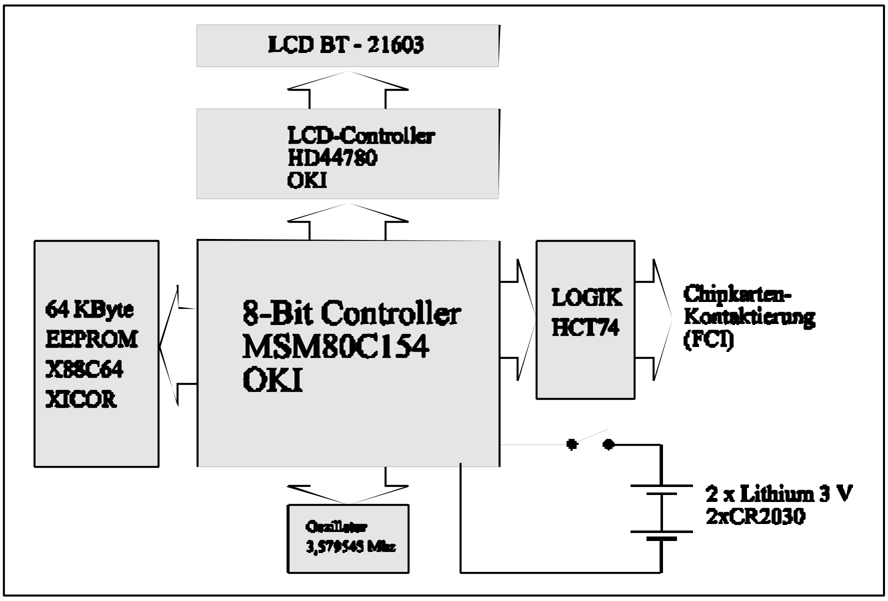


Fig. 3: Block diagram of the old product

Last not least, the power supply was a problem. There is a strong standard requirement that such cards should operate with stable operating voltage of 5V independent on the battery status. Therefore a power control had to be implemented resulting in still higher costs especially for this discrete solution. In addition, the reliability of reading could be improved.

The company was going to lose market share rapidly if it did not at least match the technology of the competition.

6. Description of technical product improvements

The objective of the Application Experiment was to overcome the technical and competitive restrictions described in the last section and to enhance the functionality of the product. In detail, all requirements according to the specification of the German Credit Commission "ec card with chip" (ISO7816) should be met.

The following additional functional features had to be implemented:

- Communication protocol according to the standard (ISO7816)
- Reading and decoding of information stored in the chipcard
- Control of LCD display
- ASIC internal power supply for chipcard (in order to meet the strong 5 V stability requirement)
- Maximum battery life

The miniaturisation and the functional enhancement was only possible by implementing a mixed signal ASIC into the system substituting the discrete components in this way as shown in Figure 4.

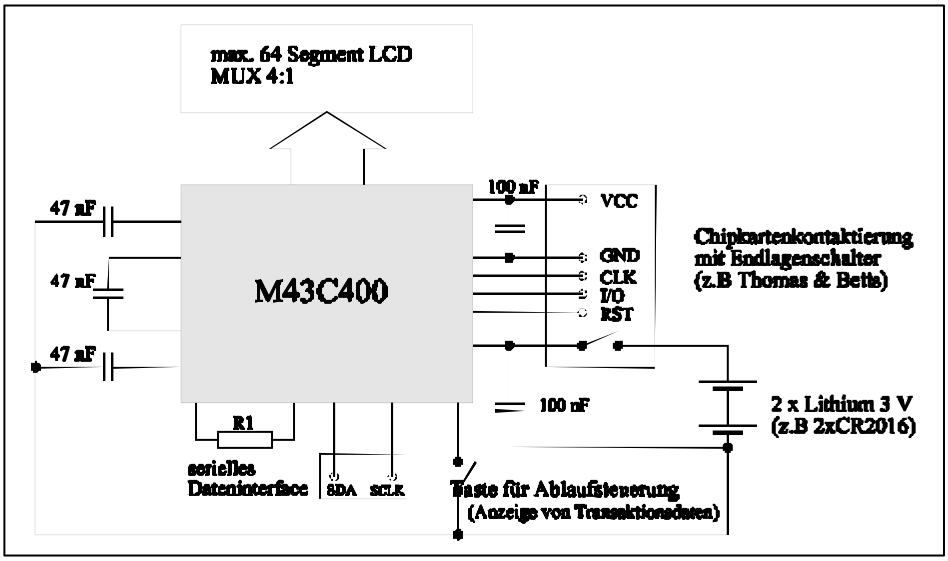


Fig 4: Block diagram of the new system

The Controller-ASIC performs the following tasks within the communication procedure with the chipcard put into the reader:

- Sending of commands to the smart card (Answer to Reset, Select File, Read Binary),
- Receiving data from the chipcard,
- Validity test of read data
- Data decoding
- LCD Control

Finally, the reader unit displays the balance or any other information on the LCD display, e.g. the 15 previous payments, the last three charging transactions of the GeldKarte or account numbers etc..

The ASIC solution is characterised by the following features:

- combination of all functions on one single chip, resulting in a drastic decrease of the number of components needed (12 instead of 48)
- New housing having a smaller size
- Improved reliability (less components)
- Increase of battery life expectation
- Improvement of recycling (smaller Lithium cells)
- decreased production costs (40%)

Figures 5a and 5b show both PCB sides of the new solution with ASIC. The ASIC has been mounted in COB technology as die on the PCB and is sealed.

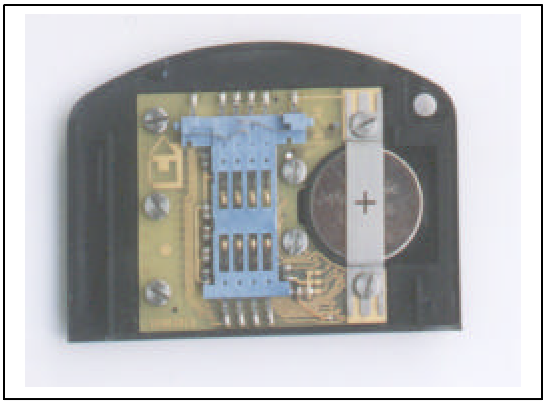


Fig.5a
Upper side of the new PC

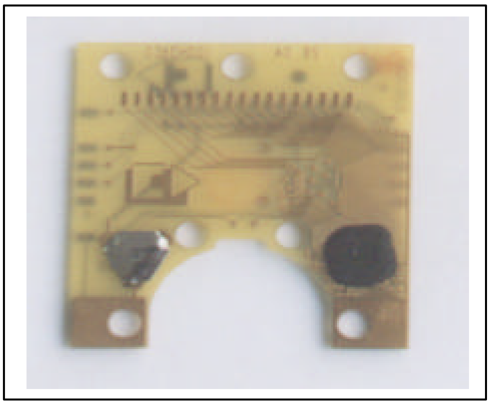


Fig. 5b
Bottom side of the PCB (with COB ASIC component)

Compared with competing products, the new solution has the following advantages:

- Enhanced functionality, for example
  * display of balance **and** transactions
  * capability to display the German phone cards balance
- Easy and comfortable operation by a single button
- Minimal number of external components
- Possibility to use the ASIC in other products (for example travel clocks or organisers)

Figure 6 shows the complete housed solution with an inserted chipcard.

Fig. 6: The new chipcard reader unit

7. Choices and rationale for the selected technologies and methodologies

As described above, the use of discrete standard components (Controller 80C154, external EEPROM as program storage, LCD-Driver, Logic-ICs, quartz oscillators) resulted in a complex PCB solution which made the product expensive and more and more uncompetitive. Therefore, we had to look for a highly integrated solution with an embedded microcontroller core. The realisation on the basis of embedded control - the monolithic combination of a modular and variable microcontroller structure with customer-specific periphery - was the key for optimal system solution.

Only this system structure helped to overcome the size and price problem for the chipcard reader unit. Also the implementation of glue logic functions into a FPGA would have required the additional use of a microcontroller.

In addition, the analogue parts would have remained unchanged. Therefore it was not possible to go this way. In order to miniaturise the system and to solve the strong voltage stability requirements, a special voltage control unit had to be developed as an integrated part of the system.

The three requirements:

- reasonable price,
- embedded microcontroller,
- implementation of analogue functions

and last not least the expected high volume production resulted in the final decision to select a mixed signal ASIC concept with an embedded microcontroller core. Further reasons were:

- higher reliability of the system
- improved EMC qualities through increased integration
- reduction of power consumption
- higher system clock

The selection process of the microcontroller core was one of the key decisions within the project. The controller core had to meet the following requirements :

- possibility to add digital and analogue components
- on-chip LCD driver (7 segment display, min. 6 digits)
- a minimum program memory (ROM) size of 4 Kbytes
- clock rate higher than 1 MHz
- on-chip clock generation with an absolute minimum of external components (resistor, capacitor)
- Input/Outputs especially for smart cards
- possibility to regulate the voltage according to the smart card specification (exact 5V)
- testability of the Controller-ASIC and the complete chipcard reader

Among all possible components (e.g. 8051 core) the MARC-4, a 4 bit controller core offered by TEMIC was chosen. This core allows a customer-specific system configuration adapted to the special project requirements.

On the other side it is not over-dimensioned, guarantees a minimum chip area and has a very low power consumption. This results in an optimum cost-performance ratio for the customer.

The modular microcontroller MARC4 consists of an area-optimised core of a 4-bit processor in Harvard architecture and a set of I/O components capable of being enlarged. Parallel access to the core internal data RAM and program ROM, double stack and other hardware modifications guarantee a high efficiency. The configuration of the system is shown in figure 7. Peripheral units can be connected to the system communicating with the core by a bus system. Some available units are different parallel ports, timer, counter modules and LCD Controller. On-Chip-EEPROM structures, LED driver and analogue-to-digital converter are available. Analogue or digital customer-specific substructures can be added depending on the customer needs.

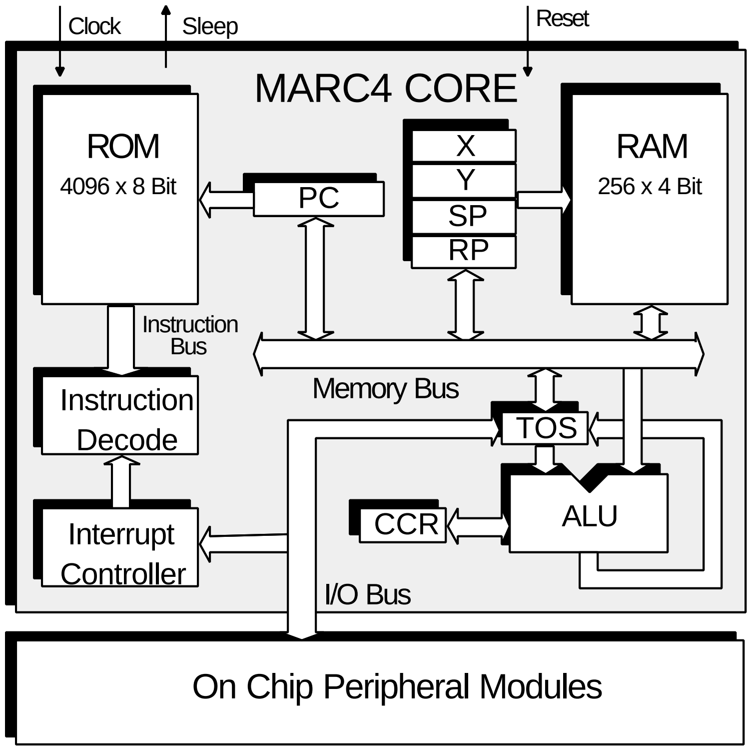


Fig.7: MARC4 Core

The core consists of an ALU, an expandable 12-bit program counter, a program ROM (capacity can be modified from 2 to 10K words), data memory, stack controller, interrupt controller, instruction decoder and other optional components (e.g. oscillators with watchdog control, voltage control, test select).

The 4-bit-CPU of the MARC4 has three separate bus systems:
- Instruction bus,
- memory bus
- I/O-Bus

This allows a parallel communication. Furthermore, an instruction pipelining is implemented. The MARC4 is a stack-oriented microcontroller with expression and return stack. All on-chip peripheral modules (e.g. clock generator and RESET) are placed round the core.

The MARC4 can be programmed with assembler or a 4-bit modification of FORTH (qFORTH). This language is very effective for real-time data processing.

Taking into consideration all aspects of the "pocket-reader"-project additional problems had to be solved :

- To supply a smart card with a sufficient amount of power a voltage of 5 Volt +/- 10 % is needed. Because of the limited size of the smart card readers, only lithium-cells could be used. However, the standard voltage of a lithium-cell is only 3 Volt. Using two batteries in series connection supplies up to 6 Volts. Therefore, the final regulation had to be done by the controller ASIC.

- It is one special characteristic of smart cards, that a frequency of about 1 MHz is an essential working condition for the proper operation of the smartcard controller. The usual frequency of a 4 bit low-cost-controller is 32 kHz. So a 32 kHz clock quartz crystal is used as the frequency controlling component. Therefore it was necessary to develop an additional oscillator for the Controller-ASIC. This oscillator delivers the 1 MHz clock and requires only a simple SMD-resistor as external component.

Figure 8 shows the ASIC with all implemented sub-blocks.

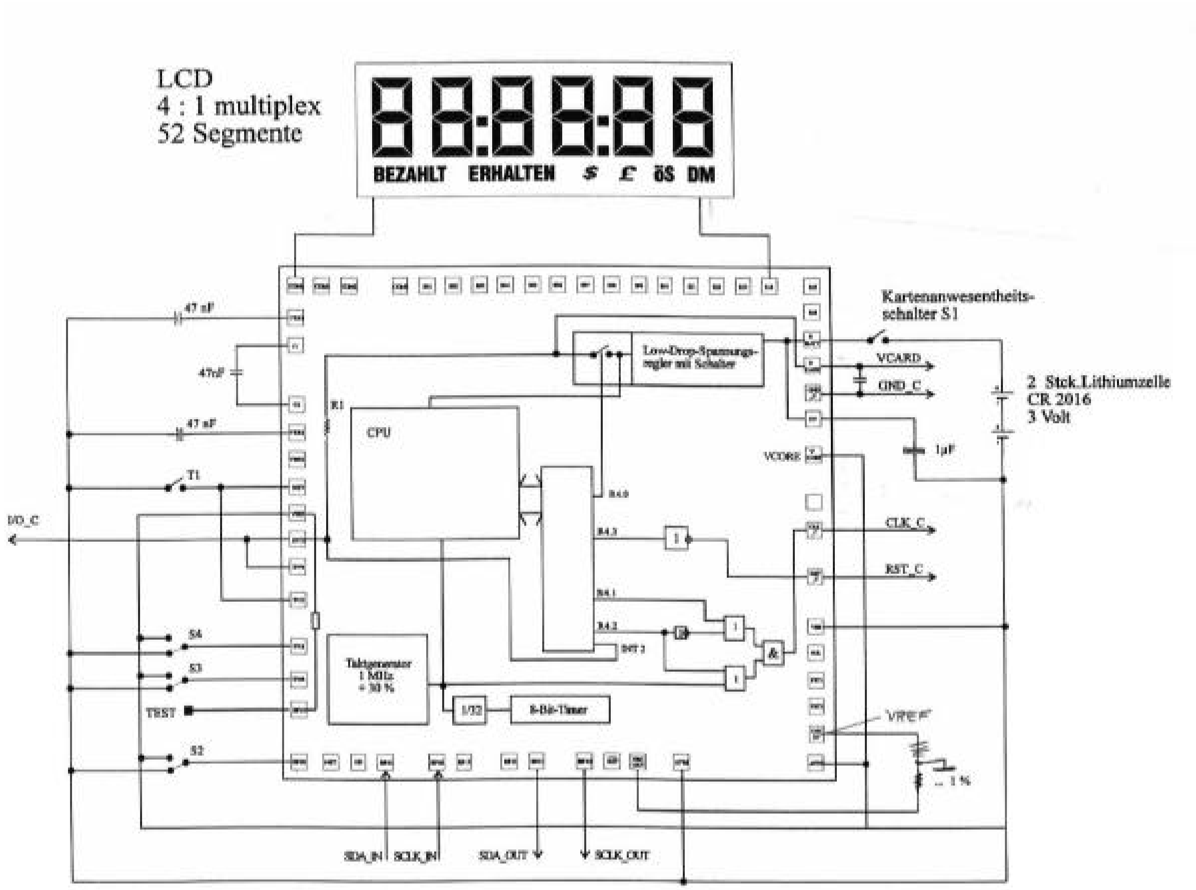


Fig. 8: Block diagram of the ASIC

The specified main parameters for the ASIC were:

? Operating voltage 3 V/<2mA
? Oscillator 1-4 MHz
? Memory: ~2kBytes ROM, 40 Byte RAM
? Inputs/outputs for chipcard (Power supply, Reset, CLK, I/O)
? Voltage generation for chipcard 5V / <10mA
? LCD Control (6 digits, 7 segments, display of special characters)
? Inputs and outputs for keyboard
? Embedded microcontroller core

For the manufacturing, a 0,8 µm standard cell CMOS technology delivered by TEMIC/XFAB was selected. The analogue cells for the voltage control were especially developed for this project. The total manufacturing costs were 37k€.

For the complete design (digital and analogue parts) Mentor software was used in all stages of the design flow, starting from the schematic entry up to the layout generation. The tools were available at the subcontractor. The design work for the digital part was made at gate level with schematic entry. In discussions with the subcontractor we decided not to use a VHDL description, because the structure of the system would have not justified an effective application.

During the project, all digital and analogue parts were simulated and checked against the specification continuously. At the end of the project, a chipcard reader prototype was built and all functions were tested successfully in a complex field test.

Tools existing in the company were used (Eagle) and in addition the use of gFORTH for the microcontroller was required.

8. Expertise and experience of the company

Cards & Devices is a small, microelectronics application oriented company with 5 employees, two of them are electronics engineers. Both were involved in the development tasks for smart card readers and interface devices for smart card applications, starting with the first system design up to the final industrialisation process. The engineers are experienced in digital and analogue designs based on the use of standard components. Of course Cards & Devices is are able to manage such kinds of projects.

All products were designed on the basis of SMD-Technology and the use of Multi-layer-PCBs. We were able to do that completely in-house. Corresponding PCB development tools are available in the company (EAGLE).

Most of the products were based on the 8-Bit microcontroller 80C31 by the Intel company. Thus, we had experiences in application and programming of microcontrollers in Assembler and C.

In the area of ASIC design there was no prior experience at all. We were not able neither to select and to handle tools, to do the ASIC design and simulation, nor to test such a chip. The use of embedded systems, i.e. controller cores, was completely unknown for the specialists of Cards & Devices.

Also the finally selected COB technology for the product was new for the company. In addition, the programming language gFORTH, which was needed for the software development had to be introduced. However, this was not a major problem for us.

Management knowledge for such a kind of project was not available. We were not able to make a proper planning, to do a realistic economic and functional market investigation, to select subcontractors and to guide such a project ourselves. Also the optimum for a division of work between a subcontractor and our company was not clear.

Therefore, a detailed project management training was required, focussed at ASIC projects with the main topics project planning, workplan definition, economic calculation, selection of tools, interfaces to a subcontractor and internal project control issues.

9. Workplan and rationale

Together with the TTN (and subcontractor) a workplan was made for the project and the collaboration between FU and subcontractor.

This project plan was divided in the following tasks:
Task 1 "Management" covers the technical and project management, such as the contacts to the TTN, reporting and dissemination activities, but also the managing and economic aspects of a technology selection (setup of workplans, economic forecast etc).
Task 2 "Training" includes the introduction training courses to Technical management, principles of mixed signal ASIC design, handling of tools and test strategies.
Task 3 "System specification" includes the determination of parameters and resources of the new product, the basic structure, the selection of components, manufacturers and tools. It also covers planning of test, diagnosis and simulation strategies.

In detail had to be specified:

- functionality to be implemented into the ASIC
- software modules (basis: standards for electronic purses, defined by the banks)
- the power consumption of the components and especially the ASIC,
- I/O definition of the ASIC
- external wiring
- power supply and voltage control
- LCD control unit

Task 4 "Design" comprises all design and simulation activities for the analogue and digital part as well as the programming in FORTH. especially, the additional logic and analogue blocks to be added to the core had to be designed (e.g. voltage regulation, serial ports for data transfer). Furthermore, the mask to program the MARC 4 internal ROM was defined. Of course the final layout generation, post-layout simulation and the manufacturing of prototypes (plus wafer test) are included in this task.

Task 5 "Manufacturing, evaluation and test" contains the ASIC test, the board prototyping for the chipcard reader and a complex field test of the whole device.
The original workplan and its final realisation is shown in the next diagram:

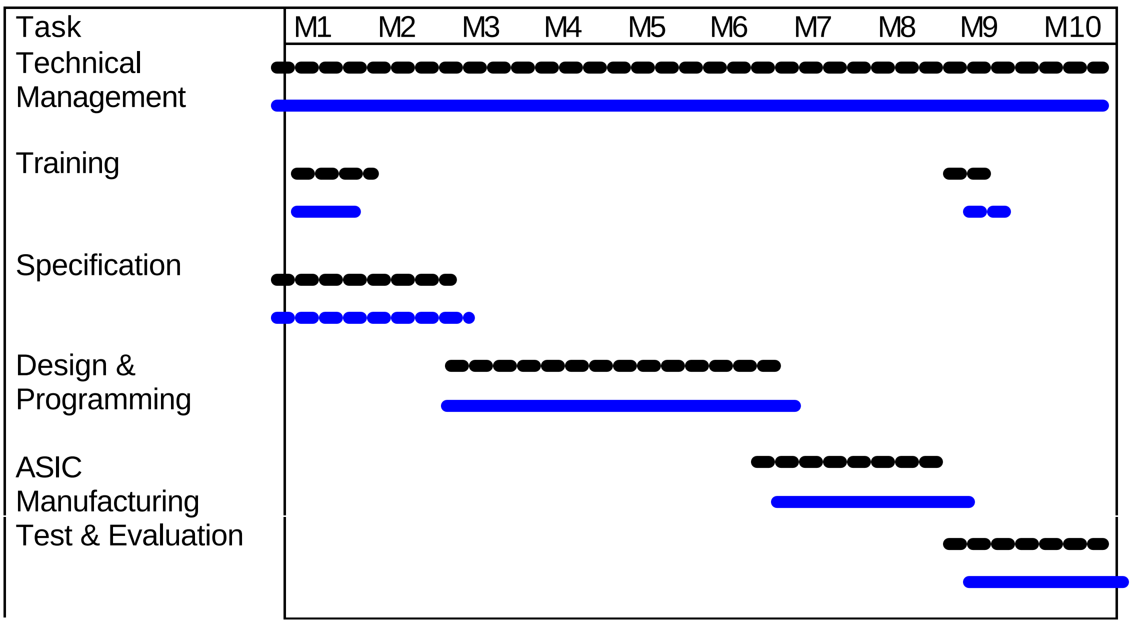


Fig. 9: Workplan of the project:

Planned:
Real:

As can be seen, the project was done nearly as planned. This was possible because of an excellent co-operation between all involved parties: the First User, the TTN and subcontractor and the XFAB/TEMIC.

During the preparation phase of the Application Experiment and within the specification task which included also the final choice for design methodology and ASIC manufacturer, a risk assessment and a contingency planning was made together with the subcontractor and the TTN.

The result was an intermediate test step for the final system solution. Together with the subcontractor, a hard-wired breadboard circuit model consisting of the MARC4 core and discrete components simulating the additional ASIC components was built up. This allowed to check the hardware under real conditions which guaranteed the functional and electrical correctness of the design and the developed software much more reliable than only an -even very detailed -simulation can do. The resulting higher effort was justified, because the design risk could be minimised in such a way.

For the ASIC design several iteration cycles for simulation and modification were planned and used.

In order to be sure that the design really met the requirements of the banks, the final functional specification and the technical parameters were presented to the Central Credit Commission of German Banks e.V. (ZKA/VÖB) which is responsible for the introduction of such equipment in Germany. They agreed with our solution.

The ASIC realisation was based on the use of the *tested* component library of the manufacturer. Modified analogue block and elements were simulated, their correct behaviour was confirmed by the manufacturer. In addition, the subcontractor had the *necessary design experiences*. Thus, a possible library or design risk could be excluded (or at least reduced to an absolute minimum).

In a common specification review between First User, subcontractor, the TTN and the ASIC manufacturer all electrical requirements and the structure of the design were checked against the parameters of the technology. It was a common result of these discussions that there should be no technological risk. For the case of still existing errors, a second run was scheduled immediately after the 10 months schedule presented above. Fortunately, it was not necessary.

In total, the effort spent by the FU and the subcontractor were within the planned limits. However, we had planned more time for design iteration cycles than really needed. This resulted in a reduced effort for the design task (104 instead of 166 persondays). Table 1 shows the details (all information in "person-days"):

Task	**First User**					**Subcontractor**			**Totals**	
	Role	**Effort**		**Cost (k€)**		**Role**	**Cost (k€)**		**Cost (k€)**	
		plan	**real**	**plan**	**real**		**Cost**	**Cost**	**Plan**	**Real**
Management	Responsible	28	20	4,8	4,6	Assistance	0,9	0,9	5,7	5,5
Training	Participant	32	30	5,7	5,5	Responsible	13,6	13,6	19,3	19,1
Specification	Responsible	34	34	8,0	7,8	Assistance	1,8	1,8	9,8	9,6
Design	Responsible	166	104	17,6	16,6	Assistance, layout generation Manufacturing	24,2 37,0	22,8 37,0	41,8 37,0	39,4 37,0
Evaluation	Responsible	40	35	10,7	10,5	Assistance	4,5	4,5	15,2	15,0
Totals		**300**	**223**	**46,8**	**45,0**		**82,0**	**80,6**	**128,8**	**125,6**

Table 1: Division of work

The project was carried out in all tasks in close co-operation between First User and subcontractor. The subcontractor was mainly responsible for the training activities. The specification of the functions to be implemented into the ASIC and the block structure itself was done by Cards and Devices. The subcontractor assisted in this task by defining the final structure of the ASIC (selection of macro elements available in the core library, definition of additional cells to be designed etc.). First of all he assisted to harmonise functional features and realisation capabilities offered by the technology.

The engineers of the First User designed and simulated the digital part of the ASIC. The subcontractor assisted as necessary (from full assistance at the beginning up to only help on a consultancy basis at the end). The set-up of the MARC4 program in qFORTH was completely in the responsibility of the First User. The analogue part of the system was also designed by the First User on paper. However, the implementation into the ASIC, the simulation and the design of additional analogue components was carried out by the subcontractor together with the First User, who learned in this design step analogue design and simulation methodologies. The objective was to become able to design analogue blocks in the future which can be implemented into an ASIC without problems, to get an understanding about the essential analogue design features and to define requirements for analogue cells to be designed.

The complete layout generation was done by the subcontractor.

Based on the test training course, the engineers of Cards and Devices tested the ASIC and the prototype solution. Already in the design task, First User and subcontractor defined a test program with a high fault coverage rate. Finally, a field test under real conditions was done.

Cards & Devices was responsible for the management. The subcontractor assisted especially in issues related to ASIC technology. Contacts to the foundry were organised by the subcontractor. However. the First User took part in order to get the necessary management know-how for future ASIC projects. Summarised, the detailed partitioning of work was as follows:

Task	**Cards & Devices**	**Subcontractor**
Management	Project related management	Contacts to foundry
Training	Participation in training courses	Management training ASIC design & Test methodologies Introduction to the tools
Specification	Functional specification	Assistance in technology related tasks
	Specification review	
Design	Digital design and simulation Set-up of simulation test patterns Programming MARC4 Getting overview in analogue ASIC design, simulation, test and layout generation principles	Design assistance with decreasing intensity Migration to ASIC layout
	Design review	
Test and Evaluation	ASIC test (PCB based) Field test (product oriented)	Assistance

10. Subcontractor information

Cards and Devices is a strongly product-oriented company with technology know-how in all kinds of PCB and microcontroller technology. The staff is familiar with analogue/digital design strategies, based on discrete components. There were no experiences in ASIC technologies, neither from the management, nor from the technical point of view.
Our intention in the Application Experiment was to learn how to manage such a project and to become familiar with ASIC design and the use of tools. Furthermore, we were interested to

gain experience in test methodologies. The objective was to be able to design digital ASIC parts ourselves and to become a qualified partner for a design house when discussing analogue ASIC realisations. We did not want to become ASIC designers in all design steps at all. Layout generation should be done also in the future by an experienced subcontractor. However, we wanted to be able to manage such a process from the first ideas up to the product test. That's why we were looking for a subcontractor with the following competencies:

- Experiences in training activities for mixed signal ASIC design methodologies and management of such projects
- Know-how in "Learning-by-doing-methodologies" for this kind of work
- Long-time experiences in co-operation with ASIC customers, especially SMEs
- Know-how and references in mixed signal ASIC design/simulation and the application of embedded microcontroller cores
- Independent design house with good relations to several ASIC manufacturers (not only to one of them)
- Application-oriented technology know-how (how to implement and to test such a component in the final product)

Starting from this selection criteria, GEMAC was chosen as subcontractor. The company is a SME with 60 employees, and has specialists who are experienced in all kinds of application-oriented design of customer-specific electronics.

The company GEMAC meets all criteria mentioned above and has all necessary state-of-the-art design tools available. In our case, Mentor Graphics tools were used for the complete design flow. The subcontractor also has good relationships to different ASIC manufacturers allowing an independent decision which technology should be selected.

Very advantageous for us was GEMAC's existing experience in the application-oriented design of ASICs together with customers as we are. The training activities and the subsequent design assistance were based on the long-time-know-how of the specialists of this company, and were very efficient.

The main reason to select this subcontractor was that GEMAC can offer both training and application-oriented experiences. Other possible partners had either only training experiences or design know-how without co-operation references as we needed.

The subcontractor was very flexible in his work. Depending on the actual requirements, problems and the current project situation, a very dynamic style of co-operation was possible.

The responsibilities and the division of work changed over the project time. In the first training activities, we had to learn and GEMAC was responsible for the know-how transfer.
Starting with the "Learning-by-Doing steps, the situation changed. The work was now characterised by a kind of "decreasing assistance" (which was given, whenever needed).
Later on, GEMAC was again responsible for the layout generation of the ASIC (we did not want to become ASIC designers).

The contract signed between the subcontractor and Cards and Devices covered all issues of the know-how transfer and all details related to ASIC design and manufacturing. Especially, the following items were defined:

- Details and duration of the training courses (Technical Management, analogue and digital ASIC design, design tools, test strategies)
- Details of design assistance (Learning-by-doing), duties and responsibilities
- Layout generation and simulation, modalities for design release
- Project schedule and tool licences
- Support in the negotiations with the foundry XFAB

The negotiations with the silicon foundry were made together with the subcontractor. Because it was our first ASIC design, this co-operation was very helpful for us. We learned which issues have to be asked for, to select and evaluate libraries and to negotiate the ASIC preparation itself (prices, test conditions, definition of realistic schedules and deadlines etc.). Without the assistance of the subcontractor this would not have been possible

Cards and Devices owns the ASIC solution and has the right to use the microcontroller core for its applications. The subcontractor as well as the silicon foundry have no commercial or other rights to use the technical results of the Application Experiment. Penalty clauses going beyond the scope of the common terms of business were not included in the contract.

One additional reason for the selection of the subcontractor was that GEMAC as a development and manufacturing-oriented partner will be able to give direct assistance in any future projects. This will be very effective not only because of all the technical competencies available there. As a result of the Application Experiment the subcontractor is already familiar with the technical problems of the company. This will allow an effective information flow and optimal project work.

11. Barriers perceived by the company

The development staff of Cards and Devices, including the manager, are engineers, no economists. That's why the company had no psychological barriers to introduce advanced microelectronics. The First User developed and used PCB based electronic systems and microcontroller solutions before. The company had other important barriers, e.g. in the area of management and in the technical realisation of mixed signal ASICs itself.

For instance there was no idea about the necessary effort for the introduction of ASIC technology. From the management point of view, the company had the following barriers:

How to start such a project

Without knowledge it is difficult to define a realistic workplan and to estimate the costs of an ASIC project. Before the start of the AE we assumed that the costs and the risk would be extremely high and consequently exceed our economic potential- a very important psychological barrier. On the other side it became clear for us that a further positive development of our company would be only possible by introducing these new technologies - we were in a real dilemma.

The necessary effort to be spent for training courses of engineers followed by a project work that is based only on the results of such a training course is very high. Additionally, such a methodology increases the design risk. This was an important start-up barrier.
Another problem was the division between activities to be done in-house next time and those to be out-sourced for next projects.

Selection of partners

For the management issues as well as the knowledge transfer activities in all tasks Cards and Devices needed an experienced partner who was not only interested in a complete development, but also to organise an effective training. It is not easy to find somebody who combines its technical expertise with the know-how transfer. Additionally, it is risky to go to a design house or distributor who has relations only to one ASIC manufacturer.

Necessary tools, selection of technology

If you want to start a development you have to select the best ASIC technology for your project. The problem was to evaluate available technologies. We neither knew the different mixed signal ASIC technologies, nor the most important selection criteria. No knowledge about software tools and libraries was available. Thus, the risk to make a wrong decision was very high.

Specification of product features
In order to use on the one side all advantages of a chosen ASIC technology, but on the other side not to specify not feasible requirements for your project, it is necessary to know all technical features of this technology. The lacking know-how in this field was a real barrier to specify the system.

Design and test barriers
Of course the missing experience in handling the tools and the lacking knowledge in design and test methodologies both for the analogue and digital part prevented the technical realisation of a project without continuous assistance by an external partner.

Financial barriers
Altogether resulted in a high financial barrier. There was a risk to spend much money for training activities, a wrong technology, and a lot of manpower for a development without the guarantee to have an improved and competitive product at the end.

All these barriers made it impossible to start a new development before, even if the company knew about features to be improved and the deteriorating competitive position on the market with the old units. The investment required for a small company both financially and there sources required with, for them, a very risky technology was perceived as an impossible risk to take.

12. Steps to overcome the barriers

The only way to overcome these barriers was the co-operation with an experienced subcontractor and a project management and design practice which was not a theoretical one, but a consequent learning-by-doing activity.

How to start such a project
When preparing the submission, Cards and Devices had a lot of discussions with the TTN regarding new innovative microelectronics technologies, especially:

- Technical possibilities, advantages of mixed signal ASICs and embedded controller cores, but also its limitations
- Overview of possible ASIC technologies, available design tools
- Risks and special features of analogue design, available microcontroller cores
- Typical design flows and test strategies
- Realistic definition of workplans, costs, duration of the project

Furthermore, a kind of "feasibility study" was discussed.

The result was the submission that was based on feasible technical and functional issues. It contained realistic estimations concerning workplan and costs, and a first calculation of the return-on-investment. This demonstrated very clearly the commercial advantage coming from the introduction of microelectronics and convinced Cards and Devices that the company really would have competitive and economic advantages when introducing the new technologies.

In this way, the initial start barrier (and the related psychological one) was overcome.

Selection of partners
When writing the submission, possible subcontractors were discussed with the TTN. In this time, Cards and Devices learnt to define the selection criteria for a co-operation. Next time,

the company can search and select possible partners and negotiate with them. The company is now familiar with all topics related to interface problems, price negotiations and the division of work. This was also an important issue of the technical management training.

Another important issue was the discussion of possible strategies for an assessment of the subcontractor’s work. The main instrument to do that is an agreement between the partners, which must specify all technical functions and parameters of the development. All duties and responsibilities must be clearly defined. This document has to be added to the formal contract.

Within the training courses, the most efficient division of work between the partners was discussed. The result was, that Cards and Devices will subcontract all activities in the future, which cannot be effectively replicated within the company, i.e. issues which are not part of the daily work, such as the generation of ASIC layouts, and such tasks that exceed the capabilities of the company (e.g. PCB manufacturing).

Necessary tools and selection of technology
The discussions with the TTN and the subcontractor gave an overview of available state-of-the-art tools and mixed ASIC technologies. The subcontractor, an independent design house, discussed all possible choices taking into consideration the special situation and requirements of the company. Main decision criteria were the functional requirements, features of the microcontroller core and the access to library elements for the analogue part.
One result was the selection of the Mentor Graphics tools. These tools offer a high flexibility for the design process, but are very expensive. Therefore, we will lease the tool also for next ASIC designs. This was not clear from the beginning. The technology and management knowledge gained in the Application Experiment helped to overcome a strong barrier: the fear to make a wrong tool investment or to select a not suitable ASIC technology.

Specification of product features
Within the training, detailed knowledge in the technical features of ASICs were transferred. Based on this knowledge, the complete functional description of the system and the block structure of the hardware (including embedded microcontroller core) were defined together with the subcontractor. Within this process the technical capabilities of the technology and the functional objectives of the project were harmonised. This removed the initial barriers for their application.

Design and test barriers
The knowledge transfer in design and test issues for mixed signal ASIC technologies was the main part of the AE. All necessary knowledge was transferred. Very useful was the application-oriented "Learning-by-Doing" methodology, because the First user did the job, assisted by the subcontractor with a decreasing intensity along the project. In such a way, know-how barriers in design and test technologies were overcome.

Financial barriers
The market investigation and the management discussions with the TTN resulted in a remarkable return-on-investment forecast for the chipcard reader units that will enable Cards and Devices to finance similar problems in the future.

13. Knowledge and experience acquired

Within the Application Experiment, Cards and Devices acquired the following knowledge and experiences:

Technical management of projects using microelectronics
Cards and Devices has now the ability to select appropriate mixed ASIC technologies and embedded components for a development project. We can harmonise functional

features with the capabilities of the technology. First of all, we are now able to define selection criteria for co-operation partners and interfaces, and we know, how to find them (not in the "Yellow pages"!). Cards and devices can set-up now realistic workplans and financial breakdowns for such a kind of project, can make investigations to evaluate the own position and competitiveness on the market and has the ability to make realistic financial forecasts for new products. Last not least, the company is now experienced in negotiations and co-operation with an ASIC foundry. This includes also a "background knowledge" in the wafer production (typical number of layers, production steps, yield, test equipment etc.)

Specification of mixed signal ASICs and embedded microcontrollers
Cards and Devices is now able to specify mixed signal ASIC projects and features for the selection of an embedded microcontroller core without essential assistance. Of special importance is the ability to specify the requirements for analogue components to be used. This is the basis for the selection of available library elements on the one side, or the interface to analogue designs or modifications of available components to be done by a subcontractor.

ASIC design and manufacturing experiences
This point covers the ability to design and simulate digital subsystems and to integrate microcontroller cores in such an ASIC project without problems. Cards and Devices is now able to program such a core and to define a necessary microprogram instruction set to be implemented in the internal ROM of the core. Other issues are the extended knowledge in synchronous system design (asynchronous design should not be done anymore) and the definition of powerful test sequences with high fault coverage rates. Our engineers can design and simulate analogue systems based on available library elements and can combine it with the corresponding digital parts of the project to a mixed signal system-As already discussed, the objective was not to become a layout designer. However, a "top level" knowledge is useful for communication with the design house, and the design process itself.

Test strategies for all levels of a development
Cards and Devices is now able to check the results against the specification of a project. The company is familiar with test methods for mixed signal ASICs starting from the set-up of test sequences with a high fault coverage rate up to the technology specific issues for the field test.

Last not least, we were introduced during the PCB prototype manufacturing into the COB (Chip-on-board) technology.

The necessary effort can be seen in the workplan. Basic knowledge was transferred in the training courses. They were very short (only a few days). The most important and effective methodology was the „Learning-by-Doing“ project work assisted by the subcontractor.
In the second period (at least for the digital and microcontroller part) the work was executed alone with the possibility to use a "telephone hotline" at any time. If problems raised, meetings were organised from one day to the other. At the end of each project task a common review of the results was organised.

The acquired know-how more or less corresponds to our expectations and the objectives of the Application Experiment which were defined when submitting the proposal. In some points, the engineers of Cards and Devices got more know-how and experiences than expected before. The Application Experiment was a success for the company.

14. Lessons learned

In this section some main rules and advises to other potential replicants are summarised:

Project ideas and ways to realise them should be discussed before the start of the project with a competent and independent partner. The result should contain the proof of feasibility, a rough specification and ideally the component types to be used. A workplan and a financial breakdown must be defined. A market survey and a financial forecast is mandatory.

? Start your marketing activities as soon as possible in order to get a precise market overview. Additional modifications of the specification might be necessary. On the other side, you can sell the products faster if the needs of the customers are really clear. In case of an ASIC, don't forget to investigate, if additional applications in other products of you company are possible. If applicable, specify the necessary conditions. The higher number of pieces will make the ASIC more economic.

? Don’t plan only the real project time, include an additional time buffer. Just a small company has always problems with other, unforeseen businesses. But also technical problems (such as additional iterations) may cause a delay. Set up a contingency plan. Don't forget to ask for the next MPW run date.

? Don't say that a small company cannot use ASICs. If you have an innovative solution and the result of the discussion with a competent partner is positive, you should start the project. We learned, that even a very small company has good chances on the market, if the technical parameters and the price of the product are convincing. It will allow you to open new market segments.

? Avoid the classic way of know-how transfer with a theoretical training course followed by own "trial-and-error" activities in the company. Use "training-on-the-project" and try to find an experienced subcontractor for both training and design assistance.

? When selecting design tools and components, ask for existing documentation and online support. Make sure that components will be available during the whole life-time of your product on the market.

? Don’t forget the later industrialisation. Define a workplan and make a cost planning. Industrialisation and marketing costs should not be forgotten. Sometimes, they might be in the same range like the development costs of your prototype.
Again an experienced partner is necessary!

? Test strategies and structures should be already discussed in the specification task. The implementation of special test structures in the design will enable you to organise a very effective component test later on, not only when testing the prototype, but also in the serial production. This investment will safe a lot of money during the whole life time of your product!

??If possible, select a subcontractor in your region. This will ease your common training and design work. However, it is more effective to invest in some trips to a real good co-operation partner than to fail with an incompetent one in your neighbourhood. In addition, the modern communication infrastructure helps to stay in permanent contact.

? After an introduction, the Mentor system can be used without problems even by a First User. It offers all necessary features for the complete design flow of a mixed signal ASIC project and is well supported. However, it should be leased from a subcontractor. In most cases, the purchase of the tool will not be effective for a company having only sometimes ASIC projects. In case of only digital systems, other PC based tools might be used (and bought). This depends on the development strategy of your company.

15. Resulting product, its industrialisation and internal replication

The result of the Application Experiment is a working prototype of the chipcard reader unit which completely matches the specification. Cards and Devices owns the product. The subcontractors have no rights on it, their role was restricted to the assistance in the know-how transfer and development process.

The marketing activities for the new chipcard reader were started as soon as possible. Already when preparing the submission we got some feedback from potential customers which influenced our final specification.

Immediately after the completion of the AE, the next industrialisation steps were discussed with the subcontractor. Fortunately, no essential changes of the prototype were necessary for industrialisation. Except some minor changes of the PCB design, the PCB prototype could be used directly for the market introduction. Changes of the ASIC were not necessary.

The product was introduced to the market as planned before 12 months after the end of the Application Experiment in April 1998. The reason was, that the serial production still had to be certified by the Central Credit Commission of German public banks (ZKA/VÖB). In addition, it took us some time to get the first serial batch from the ASIC manufacturer.

The necessary effort and the different tasks in the industrialisation process are summarised in the table:

Task	Months (relative to AE end)	Effort C&D	Total Costs (incl. material, third party)
Additional prototype field test	months 1 - 2	20 persondays	35k€
PCB redesign and manufacturing	month 3	8 persondays	
Manufacturing & test of first batch of serial ASICs	months 3-6	5 persondays	
Manufacturing of first serial products and field test, additional tooling costs	months 6-9	60 persondays	30 k€
Test program for product test in serial production	months 5-6	40 persondays	6,8 k€
Certification ZKA/VÖB	months 10-12	20 persondays	10 k€
Advertising before market introduction	continuous activity within this time	60 persondays	10 k€
Total			**91,8 k€**

A local firm is responsible for the manufacturing of the plastic housing of the Cash Controller.

The production and testing of PCBs is also done by a regional partner. The assembly, final test and distribution is organised in-house. The only industrialisation costs which will not be amortised through product cost or recovered from Gross Margin is the effort part of the field test, redesign and certification. This amounts to about 33K€.

As already stated above, it was our goal to use the ASIC itself, but also the acquired know-how for other product developments of our company. This internal replication of the AE results is of high importance for the further improvement of the competitive situation of Cards and Devices.

One of the main products directly derived from the project is our new interface device (i.e. customer terminal) for the German Geldkarte, which is used for a lot of applications, e.g. parking meters, vending machines (e.g. tickets, goods), or car washing at petrol stations. Compared with the chipcard reader, this product has an extended functionality. The current balance on the Geldkarte can not only be read, the device allows the debit, it is possible to transfer electronic money to the terminal.

This unit is sold to a lot of customers in Germany and Austria.

Another product which replicated the ASIC and design know-how is a small-sized pocket reader with an extended functionality. Compared with the "Cash Controller", additional information can be displayed, not only the balance of electronic money available, but also details (card holder details, ticket details, discount/bonus points).

Without doing the Application Experiment, we would not have been able to introduce all these products into the market.

Last not least the experiences gained in the certification process were of high importance for the certification of the products described before. The certification process was much more effective and less expensive.

Cards and Devices is now convinced, that the introduction of new technologies was a very important step towards establishing the company in the German Electronic Cash market.

16. Economic impact and improvement in competitive position

The introduction of ASIC technology was the key for an improved functionality and quality of our Electronic Cash system. Compared to our old and to other products offered on the market, the modified product will allows a better sale because of

Higher reliability and a better price - to - performance - relation of the product
The ASIC reduces the number of components from 48 to 12 for each controller. This resulted in a smaller PCB size for the new product and of course in reduced manufacturing and test costs of about 60%.

From the technical point of view, the system offers

- Communication protocol according to the actual standards (ISO7816)
- Reliable reading and decoding of information stored in the chipcard
- Control of LCD display
- ASIC internal power supply for chipcard (in order to meet the strong 5 V stability requirement)
- Maximum battery life

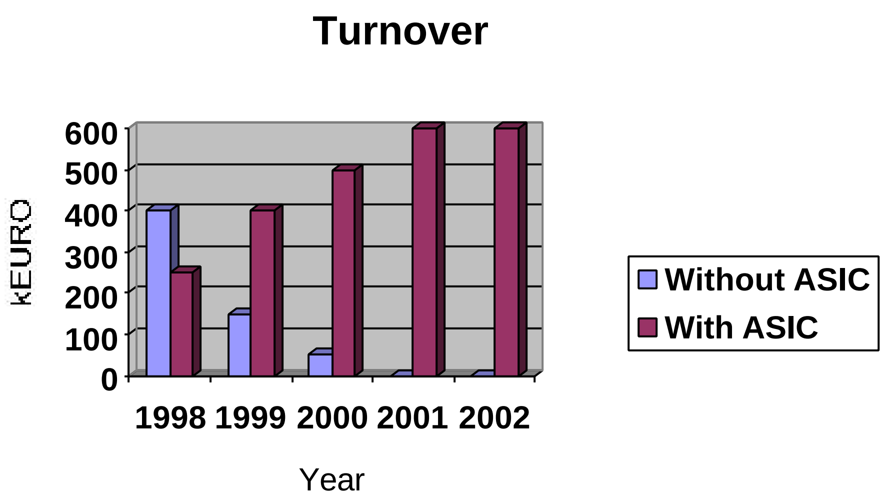
and fulfils all requirements according to the specification of the German Credit Commission "ec card with chip" (ISO7816).

With the new product it is possible to produce a series-product in mass production and to use the results for other customer-specific applications at the same time. Typical ASIC batches ordered from the manufacturer are in the range of 50.000 ASICs.

This is very important to stay competitive against the companies from Far-East. Because of the functional advantages of our products *and* the customisation/maintenance services offered to our customers it was possible to open markets in the banking, parking and vending machine sector. In addition, we sell our interface terminals for the Geldkarte to retail shops.

In order to improve the competitive situation, the economic benefits of the new, ASIC based solution were split into a lower price and additional profit.

The following diagram shows the realised and expected sales figures for the new Electronic cash controller units. Please note that the old solution has been completely substituted by the new one at the end of 1998. However, the diagram also describes the lost of market shares in case of not doing the Application Experiment.



Corresponding to these figures, the following increase of profitability was reached or is expected:

Year	1998	1999	2000	2001	2002
Increased Profitability (€)	40.000	80.000	100.000	120.000	120.000

This results in a payback period of about 2 years for the FUSE investment and a Return-on-Investment of about 350% over the expected product life time of 5 years.

In addition, Cards and Devices has benefits which cannot be directly expressed in financial data. The contacts to the finance sector and banking in the development phase of the AE opened us contacts to this sector which made it possible to enter this market with the products mentioned above extending our traditional business areas, such as public transportation.

With the new product, the development of the market share of Cards and Devices in the East German regional market and Germany will be as follows:

Year	Market share in East Germany	Market share in Germany
1998	15%	1%
1999	20%	2%
2000	30%	2,5%

17. Target audience for dissemination

There are many companies in the region East-Germany with a similar background like Cards and Devices. Small enterprises, working in special "niche" markets, and due to the history of

their staff, with a certain level of knowledge in microelectronics. They are aware of the benefits of such technologies but have not the right contacts to potential service suppliers and design houses/ foundries, and in many cases they have a high financial barrier, too. The latter one is hard to overcome, but demonstrating the experiences of Cards & Devices, they could be convinced to go the same way of integrating their digital electronic into an ASIC.
So this experiment has benefits for several companies, irrespective of the industrial target sector. Also the design methodologies and test strategies are similar in all cases. The first user itself is willing to support the activities of the TTN consortium.

Best practice aspects which should be disseminated to other very small companies cover the following issues:

- Management of mixed signal ASIC designs, especially the kind of co-operation and division of work between subcontractors and First User of this technology, set-up of workplans and cost estimations
- Internal project planning: Best approach to combine the daily business with the very time-consuming ASIC development
- Implementation methodologies for embedded controller cores
- Design and simulation methodologies for mixed signal ASICs (including evaluation of existing library elements)
- Test strategies for such a kind of design

Thus the typical target audience are companies with a product on the market, with discrete technologies (digital and analogue standard components, microcontrollers), who need to improve the product using innovative ASIC technology in order to stay competitive. They have the same barriers in management and project work and can therefore benefit from the First User's experiences.

That’s why the Application Experiment will be a good example for management as well as technical training in the field of mixed signal ASIC design.

From the application point of view, the information should be disseminated especially to companies manufacturing any kind of integrated electronic controllers. Especially for companies from the industry sectors

? Instruments and Appliances for measuring, checking, testing (3320)
? Industrial process control (3330)

can directly benefit from our application oriented experiences.

Possible dissemination activities can be focussed to:

- Companies with the same culture and size
- Small companies which are managed more from the technical point of view (manager is engineer)
- Companies with the same technology level in-house (design of analogue and digital systems using discrete components) and the same technology step
- Companies in East Germany (to allow direct information exchange)

A replication within Europe should be also possible for the same target groups as described above. The ASIC introduction is will be more and more necessary also for small companies in order to survive. On the other side, just these firms have a lot similar barriers. Thus, the experiences of this Application Experiment are useful for them. That’s why this AE has a good added value for the FUSE portfolio.