

FUSE Demonstrator document

FUSE AE No. 2006

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

FPGA for PC coupling of inductive sensors

Abstract

MFP Meßtechnik und Fertigungstechnologie GmbH develops produces and sells hardware and software for data transmission by fieldbus and length measurement. Products are sold to OEM customers and to automotive and automation industry.

In 1992 MFP developed a patented PC card IT40PC for length measurement by PC, using common inductive sensors and standard components. The patented technique replaces a large number of common analogue circuits with discrete digital components, mostly counters. Primary objective of the project was to create a new generation of the PC measuring card in order to improve it's competitiveness. A problem of the original design have been the high number of discrete components. Therefore the goal was set to integrate as many of these digital discrete components as possible in a FPGA and to improve performance of the measuring system by improving resolution and speed. Secondary objective was to acquire FPGA expertise at MFP for improvement of other products such as field bus components for data transmission in industry and petrol stations. It will allow MFP to improve performance and reduce costs of all these components.

The project proved these assumptions to be true and helped to overcome the barriers to introduce the FPGA technology. The total costs of the experiment were 68.000 ECU. The duration was 8 months. The pay-back-period is less than 2 years. With an expected product life-time of 5 years the return on investment will be around 300 - 400%.

1. Company name and address

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2. Company size

The company has 8 employees, with 5 electrical and computer science engineers, involved in manufacturing, testing and marketing. Design and management personnel, as well as a technician have been allocated to the project. The company was founded in 1988. The turnover at the beginning of the application experiment has been 250 kECU.

3. Company business description

MFP develops hardware components and software for data transmission by fieldbus and for measurement, of which length measurement is a significant part. MFP supplies its products to OEM customers, but also supplies customer-specific solutions and design support. Major technologies are discrete circuits and microcontroller and PC software. They produce about 35 different devices for industrial measuring and data transmission. MFP develops standard components for measuring and communication applications, but very often is required to adapt its products to the specific needs of its customers. Moderate quantities of the products are manufactured and tested in-house. For more complicated systems and larger numbers, subcontractors are used.

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

The market of MFP is the manufacturing industry. Our products are used in data acquisition, data transmission and automation systems. The measuring systems control dimensions of, e.g. parts that are processed by tooling machines. The measured values are communicated to a PC, using the German measurement bus. The values are then used for control of the machines or for quality assurance. MFP supplies solutions for the complete measuring chain in automation applications. Customers are the automotive and machinery industry and their suppliers.

MFP delivers mainly to the German market but also to other European countries. The companies market share in the area of industrial length measurement is about 0,1% of the European market. There are many large companies, like Siemens, Pepperl&Fuchs etc. in this market. Higher flexibility and shortened design cycles will help to extend MFP's overall market share. We expect to increase our market share by a factor of three or more, if performance and costs of our measuring system can be improved.

We expect to save up to 10% of development costs by using FPGAs. Re-programmability allows to adapt the systems to specific customer needs and help to defend our market share against big system manufacturers with very cost effective but standardised products. This is especially the case in the field of automation, which is of ever increasing importance for the measurement tool supplier.

5. Product to be improved and its industrial sectors

The PC card IT40PC couples inductive sensors to the PC by a patented procedure. Inductive sensors are used for length measurement, e.g. in quality assurance in manufacturing industries. Since in many cases the personal computer is used for data acquisition, a PC-interface with inductive sensors is required. The IT40PC is such completely unique sensor interface for a PC. There is no analogue data part and no A/D-converter, even though the sensors itself are analogue components. The patented procedure is based on the digital load of analogue sensors, which transforms a rectangular signal into impulses. The impulses are integrated, to control the oscillator frequency of the signal generator. The integrated output of the sensor is switched by a command of the controller from positive to negative polarity. The switching frequency is dependent on the oscillator frequency, which itself is dependent on the sensor and its displacement.

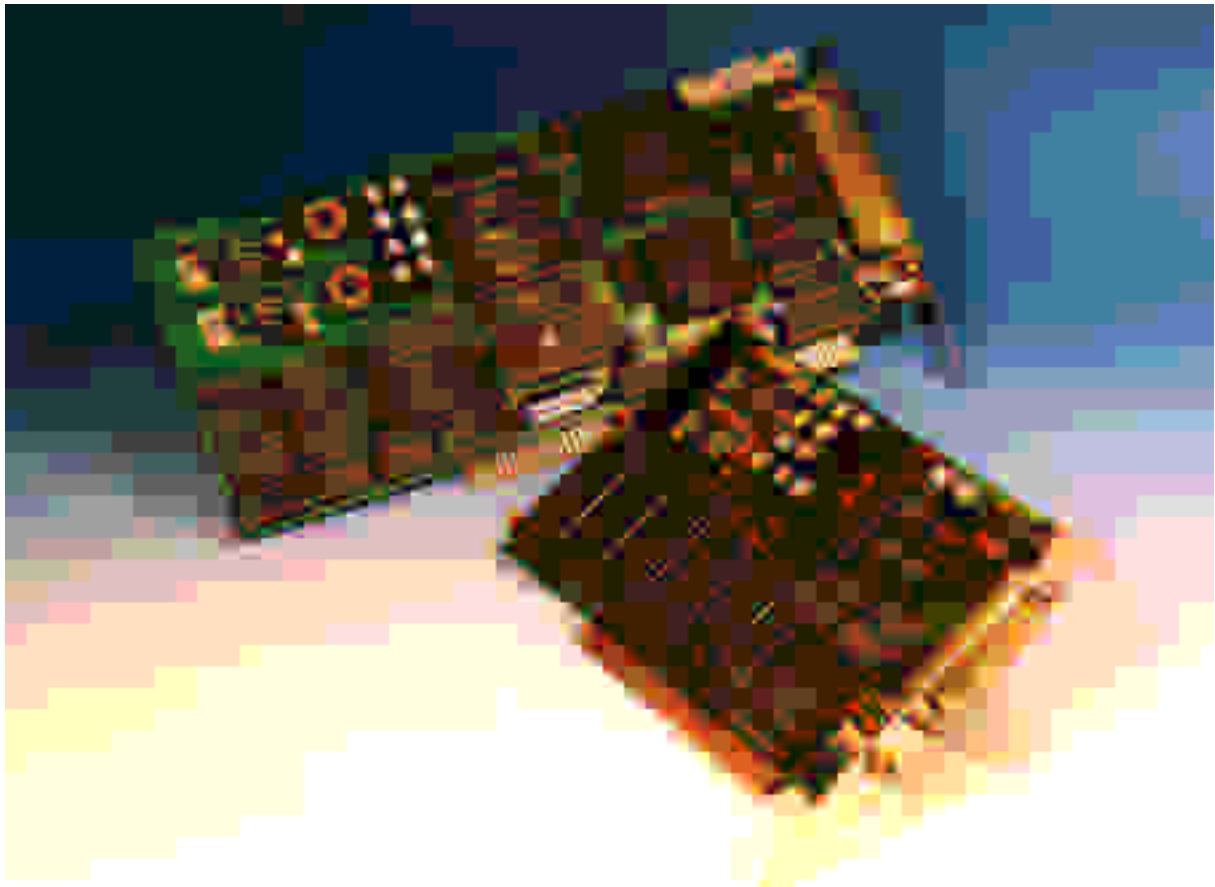
Thus the PC card has two main functions.

1. Switching the integrated output of sensor.
2. Counting the frequency of the generator that is controlled the oscillator and the sensor.

The measuring signals are evaluated by the PC. The advantages of the digital PC card over analogue systems are lower noise and drift. Its disadvantages are less measuring channels and a higher price, compared to competitors products.

The central components of the card are counters. The card to be improved, has 4 channels with 13 counters of 8 MHz. The channels have a resolution of 18 bit. The maximum measuring

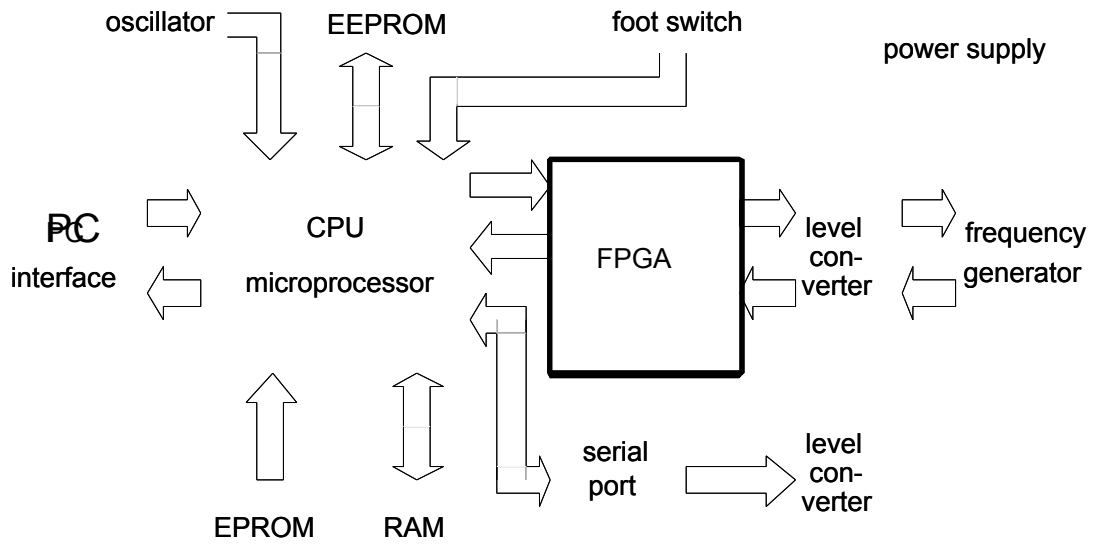
frequency is 100 Hz. The picture shows the old product (in front) and the new product with improved performance (e.g. additional channels, better performance, microprocessor for autonomous operation):



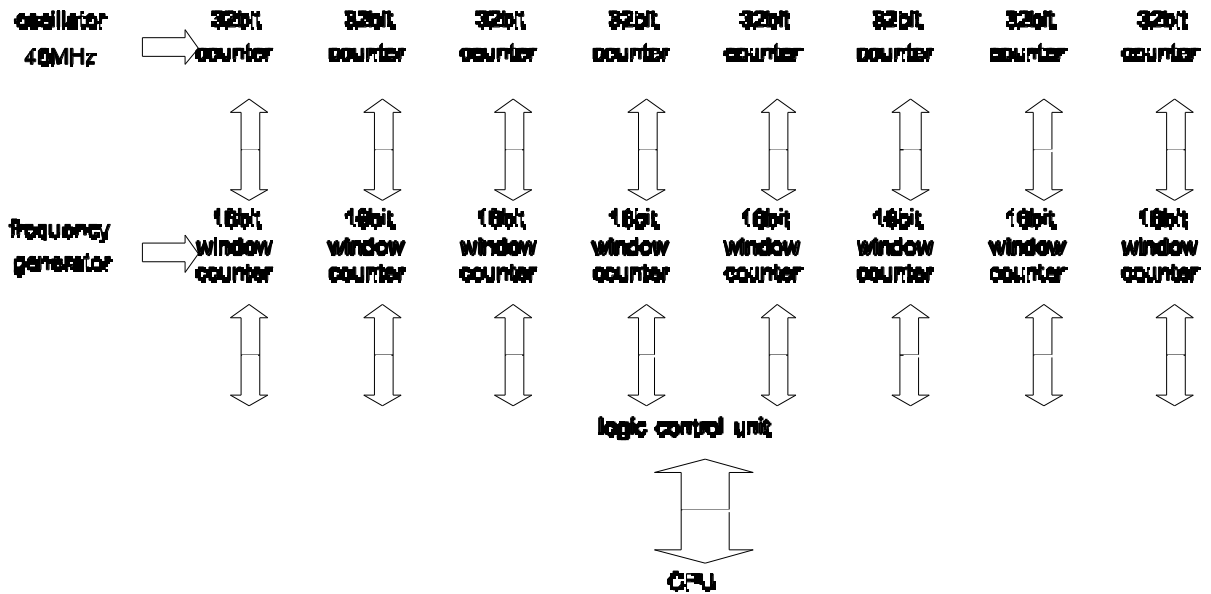
6. Description of the technical product improvements

In order to improve competitiveness of the measuring system, its price per channel, the overall number of channels per PC and the measuring frequency had to be improved. In order to enable higher integration the company integrated the timers and part of the discrete logic in an FPGA. The figure shows a block diagram of the improved product and of the FPGA.. With higher integration, the number of measuring channels could be increased to eight and measuring frequency to 250 Hz. For interfacing with the PC and for independent operation, e.g. controlled by a foot switch, a 16 bit microcontroller, memory and periphery are added to the XC3042A FPGA, which has 144 CLBs., of which 142 are used for the circuitry. This corresponds to about 2500 Gates. The layout of the PC-card is a 4-layer design with a clock frequency of 40 MHz.

PCB circuit:



FPGA structure:



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

There are three main groups of FPGAs. The first group contains antifuse FPGAs. For programming of antifuse FPGAs a special programmer is needed. Antifuse FPGAs are one time programmable. The advantages of antifuse FPGAs are small signal delay and small area. This results in high speed designs. The second group contains electrically or ultra-violet(UV)-erasable FPGAs. They are many times programmable, but also require a special programmer. Usually they are more expensive than antifuse FPGAs. The third group contains static RAM (SRAM) based FPGAs. They are programmable many times but lose the program, when the power is switched off. So they are only usable together with a processor, which loads the FPGA during system start-up.

Because it was obvious that the PC card must have a processor that may initialise the FPGA and due to the higher flexibility an SRAM FPGA was selected. One big advantage is, that in combination with the PC, updates of the FPGA can be made by software on floppy disks. Considering also availability of components and of PC-based design software XILINX FPGAs were selected. Aside from numbers, re-programmability of SRAM-FPGA's also is a major reason, not to select an ASIC. Using discrete components, the required performance and density on the PCB could not be reached. Another alternative would have been to use a microcontroller. This however would not allow to reach a sufficient performance due to a large number of parallel count-processes (8 channels), which have to be serialised on a typical microcontroller.

One basic tool in CAD is the tool, used for schematic design entry. This tool can be used to build up circuits for common digital and analogue devices as well as circuits for FPGAs. In both cases netlists are generated from a graphical circuit plan, which are the input for the subsequent design processes. A well known schematic tool is OrCAD, which is used on PC platform for common devices. But there are problems in connecting it to the XILINX FPGA tool. So MFP decided to use the schematic tool of Xilinx, which is part of the offered foundation series. The experiments showed, that indeed there are no problems in generating the netlists for Xilinx-FPGAs. The handling of the tool is similar to other schematic tools and has a useful tree structure. For design of FPGAs more functions are available in comparison to common schematic tools.

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

The company has expertise in PC hardware and software, in microprocessor technology, measurement technique and field bus communication. MFP has designed PC cards and gateways for industrial measurement and data transmission. Thus there is experience in PCB design with logic circuits, PC technology and programming languages Assembler, C and Pascal.

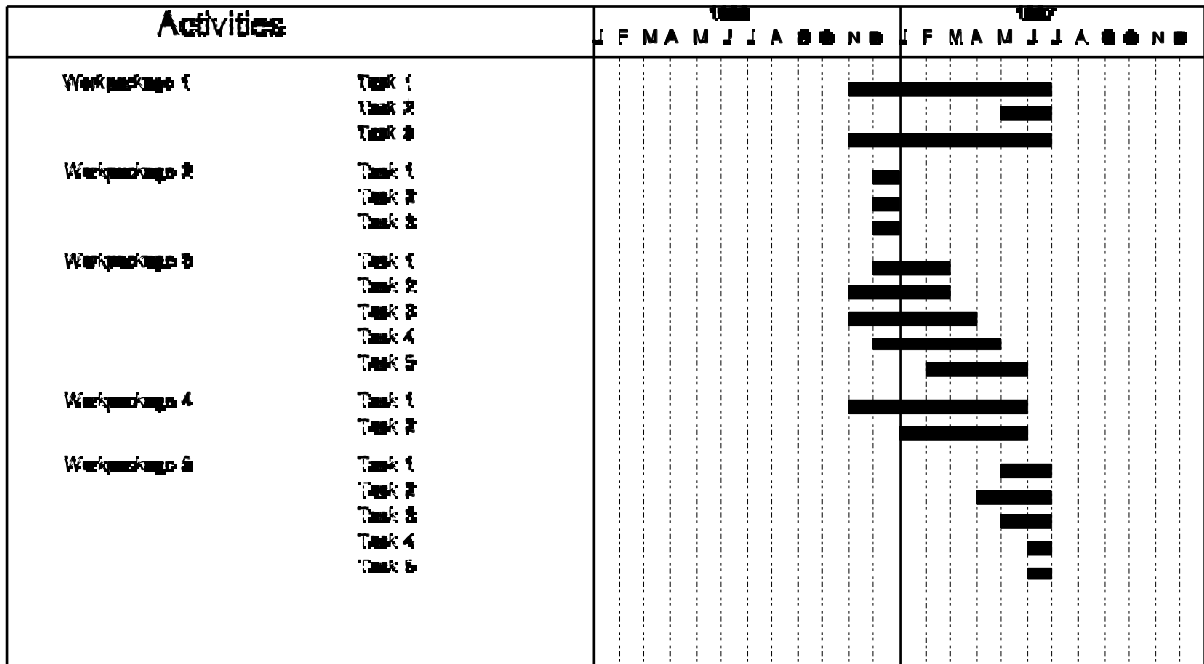
9. Workplan and rationale

The First User chose an engineer each, from the management and from development team to perform the AE. They had to :

- Manage the experiment
- Get training
- Select technologies
- Specify and develop the new product
- Replicate the new knowledge in the company
- Train personal in new technology
- Test the prototypes

The planned time scale was very short. The experience showed, that most tasks required 10% to 15% more effort than planned. It was felt, that this was due to the new technology, applied for the first time. However, the time schedule was met by allocating a higher percentage of working time to the project. The subcontractor costs did not change. The subcontractor provided the general training and training on the project, as quoted for a fixed price.

Summary of workpackages, actual duration:



WP1: Management

This task includes technical and economical project management and documentation of intermediate and final results for quality assurance and further reference. The management of the experiment was done by MFP. The actual effort was 85 person days.

WP2: Specification

Specification involves definition of objectives and required application system properties, as well as selection of appropriate technologies and design approaches. It involved specification of:

- Application properties and performance
- Electrical and mechanical properties
- Design and manufacturing flow
- Quality assurance measures including certification

During specification, the measuring system was described. The board, to be developed is a PC card with the main functions of switching the output of sensor and counting the frequency of sensor circuit. The FPGA encompasses the counters with logic control unit. It was decided to choose a Xilinx FPGA. It can be loaded by a processor without a programmer. The actual effort was about 10 person days, the subcontractor costs were about 1 kECU.

WP3: Training

During training, general and project-specific know-how on the following subjects was acquired.

- Technical project management
- Selection of design flow and design system
- Selection of components
- Design of FPGA-devices

Training consisted of a general part, on basic aspects of FPGA and a project-specific part, adapted to the concrete project.

During training by the subcontractor, important knowledge about technological, economic and management details of FPGAs and FPGA project was transferred to MFP. Now MFP is capable to plan, manage, carry out and evaluate FPGAs projects. The actual effort was about 80 person days, the subcontractor costs were about 8.5 kECU.

WP4: Design

The design was mainly done by MFP, just minor support for critical parts was given by the subcontractor. This work-package includes the following tasks:

- Design of FPGA
- Verification of specified properties

During the design phase, the PCB and FPGA were developed. The layout of the PC-card is a 4-layer design with a 16 Bit microcontroller and the Xilinx FPGA XC3042A, which has 144 CLBs. During the work it became clear, that it would be impossible to implement all functions into the FPGA. So the revised approach was, to implement only one large high speed counter and to use this as a reference. The actual effort was about 80 person days, the subcontractor costs were about 2.6 kECU.

WP5: Evaluation

Evaluation includes prototype production and different tests to assess the new technology with respect to feeding systems. The following test phases took place:

- Laboratory tests of individual components
- Tests within example system

MFP decided to make tests directly on the developed board. A test- and loading-software was written, which loads the circuit as a HEX-file into the FPGA. The test result for the hardware was OK and the aim of the project was reached. The new product will have much more performance than the old one. The tests however also confirmed, that the real behaviour of the FPGA can only be tested inside the final application. Timing problems were discovered, because the repeatability of the placement and routing was not given. The actual effort was about 40 person days, the subcontractor costs were about 1.3 kECU.

10. Subcontractor information

There is a gap of knowledge between this specific application experience of the first user and technological information, which is need for implementation of FPGAs. This has to be filled by the subcontractor. An exchange of knowledge from the subcontractor to the First User took place on:

- Types of FPGAs
- Advantages and facilities about FPGAs
- Help on searching for special information
- Help on choice of the FPGA
- Know-how on tool installation.

The subcontractor provided general information before and at the beginning of the project on these subjects and some extensive training courses about FPGAs in general and the design of Xilinx FPGA. In addition, the subcontractor gave support (coaching) during the project. During the project the intensive contact and several discussions with the subcontractor were very important. The subcontractor has to be available during the whole project and must have an overview about problems with FPGAs.

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

Knowledge barriers

The general options of FPGAs, to integrate a number of discrete components and re-programmability, which relates it to software development were known by MFP. However, concrete approaches to the new technology were not present. MFP had no management, design or procurement experience with FPGAs. In detail, there were the following major barriers to introduce FPGA technology:

Psychological barriers

- Will reprogrammable FPGAs be reliable?
- Will flexibility be sufficient to consider all customer needs?
- Is the technology accepted by MFP's customers?

Technology barriers

- No CAD-system for FPGA
- No tools and expertise for handling complex FPGAs packages
- Limited technical management capabilities
- Primitive project management skills

Financial barriers

The financial barrier, especially since the return on investment could not be relied on without experience in using FPGAs in the measuring market segment by small companies, was important.

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

The process of overcoming the barriers in adopting the new technology, faced by MFP, started with the initial contact with the TTN. During this process the company was provided with training by the TTN on the following topics:

- The available technologies and their merits
- The economic and business implication of adopting the new technology
- Technology and subcontractor selection process

The First User conducted, with the support of the TTN, a detailed feasibility study into the improvement of their original measuring card and also other products in the future. This study has resulted in the selection of FPGAs as the base for their new measuring card and covered the technical and economic aspects of adopting the technology.

The initial training and the feasibility study allowed the First User to address and overcome some of the barriers listed in section 11, especially the knowledge barriers, and some of the psychological barriers.

The deciding point to overcome knowledge and technology barriers was the contact to the subcontractors. With common training and training on the project all knowledge barriers were overcome. This, in connection with personal training and the prototypes, was the base to overcome most of the psychological barriers.

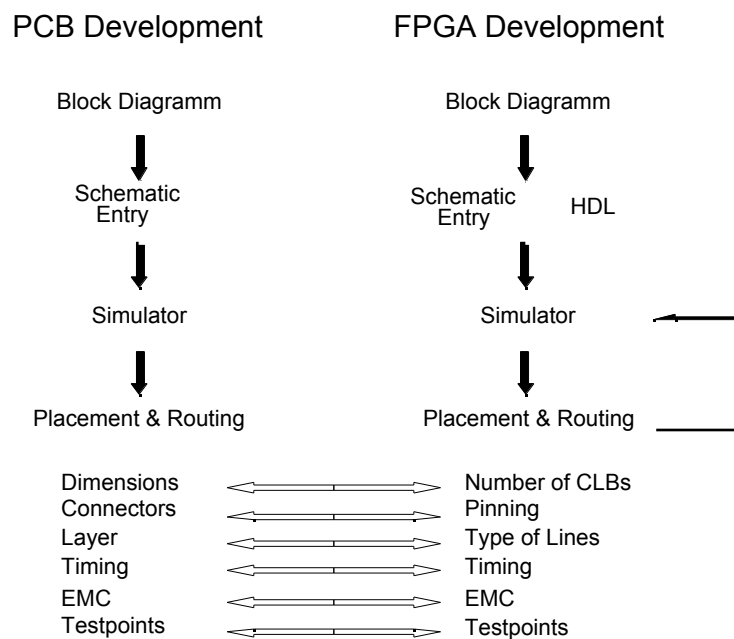
The FPGA and PCB timing were the main technical problem in such designs and it would be helpful, to get basic information about timing by a simulator. The First User has no simulator for PCBs. The used CAD tool for development of PCB was not up to date, specially when

multilayer boards with higher frequencies and many components have to be considered.

A market overview was made, to find the right FPGA tool and technology. The First User decided to make the layout for a 84 PLCC FPGA in order to be variable for the future. This pinout is available for all Xilinx FPGAs. There is the chance to avoid big changes in layout, if the FPGA type has to be changed. The choice of the XC3042A with medium performance and medium price was made.

13. Knowledge and experience acquired

The first user reported a similarity between PCB and FPGA projects, such that many measures, known from PCB design can also be applied to design and development of FPGAs. It was one aim of MFP to deeply understand the new technology. The figure shows the similarity of both design flows:



Key issues of skill, acquired were:

- Management of a scheduled FPGA development project
- Assess CAD-systems and their features
- Specifying a new product on system and subsystem level
- Get skilled to use First User's CAD-system
- Common knowledge about FPGA-technologies

14. Lessons learned

The involved staff of MFP was highly motivated, but every-days work made it hard to concentrate on acquiring knowledge in the new technology.

It seemed to be dangerous to realise too many functions in one step. The aim of the project was to get experience in application of FPGAs and to develop a new product, that can be sold. Therefore, functionality should be considered very carefully.

MFP mainly learnt technical lessons:

Follow the recommendations of the supplier in configuration of your development system.

Otherwise there may be some hardware compatibility problems. Individual configurations may not be tested sufficiently and support may not be easy. Ask the supplier for the tested configuration.

Choose all CAD tools from a single supplier, so that there are no problems in linking the tools. If you have experience in PCBs, start with the schematic tool to design the FPGA. You will better understand the function and facilities of the FPGA as well as optimisation results.

Start with design examples given by the supplier. Change the example step for step, afterwards you understood the behaviour. Build up modules, which you can simulate and test as single component. Define test points and connect them to special pins for being able to observe the signals by an oscilloscope.

For simulating and testing the FPGA design you have to use test vectors. With test vectors you specify the required input pattern and the expected outputs of the device. Note that the simulator cannot test a mode in the design, if you don't write a test vector to force that mode of operation. So ensure that you test all functions of the design and write complete sets of vectors. Take care about power-on-status of your components and give pre-sets and pre-loads to avoid unknown status.

15. Resulting product, its industrialisation and internal replication

The First User produces the products by themselves. By doing the AE completely on it's own, with just assistance by a subcontractor, MFP owns the entire rights in the development. Furthermore a patented device has been chosen, which is protected by international laws.

MFP has access to all design and development tools. If any not foreseen additional work needs to be done, the TTN and other local technology providers may be asked for help. The new measuring card replaced MFPs old 4-channel card, so that no market introduction was required, but of course the new features had to be emphasised in publications and newspaper articles.

The chosen FPGA does not require programming during production. It is rather loaded by the micro processor during system start. All future devices and hardware modules developed by MFP will have processors on board. The reasons are:

- The trend for more intelligence of peripheral devices
- The necessity of intelligent boards when using new operation systems like WINDOWS.

The new product is on the market and in the meantime completely replaced the old measuring card. It is also planned to use the FPGA in another measuring card, which evaluates the signals of digital length measuring sensors. These optical sensors are used in every tooling machine to control the position of the slide. Because of increasing speed of all movements in manufacturing and automation, the electronic also has to become faster. Therefore, the First User wants to use FPGAs.

Furthermore MFP wants to do fast operations in data transmission with FPGAs. They produce about 25 different devices for industrial data transmission, ten of them could be improved by FPGAs. It is planned to start with a PC card for data transmission used in the industry and in the field of petrol station technology. On the sector of petrol stations one or two more products are suited to use an FPGA.

For these projects the built up development system for Xilinx FPGAs will be used. The contact to the tool vendor and the upgrading is guaranteed. The first update of the development tool already received. Also the narrow personal contact to the subcontractor, which was made during the AE, will be continued. Other projects in co-operation were started.

16. Economic impact and improvement in competitive position

With application of FPGAs the First User has gained technological and economical

advantages.

The first advantage is the bigger market for the new product. Because of more channels and higher measuring frequency the market of dynamic and multipoint measurement will be opened. This is the special market for PC applications because of automatic systems, which use the PC for measurement and control.

Furthermore the concept of FPGAs together with a microcontroller on board will enable the PC card to run under WINDOWS. The last year showed, that WINDOWS will be the future operation system for PCs. Because of its structure this system needs intelligent cards for operation. The developed 4-channel card first is not able to run under WINDOWS.

Higher performance and the new concept of the PC card developed in the FUSE project will open a bigger market for the First User. It is expected, that the card will be the leader product in technology. This is a good supposition to heighten the market share in PC length measurement.

It is estimated that the market share in Germany can be increased up to 1 % in the next 5 years. The total German market for PC length measurement has a volume of about 60 million ECU for the electronic components. Much more business can be made by engineering using the new PC card. Also in the European market the chances are very well, because the new technique is protected by an European patent.

With application of FPGAs the PC card and other products can be produced with lower costs. First the component costs will be reduced about 30%. Furthermore the mounting costs will be reduced about 80% and testing costs about 30% because using only one component instead of 8. The expected total cost reduction will be about 40% in comparison between new and old technology. Increased functionality and performance of the new card allows to sell it at least for the price of the old product, but it is also an improvement for the customers, because the price per measuring channel drops to about 50% mainly because the number of channels per card has increased.

Small companies like MFP are orientated directly to the customer. Because of the special wishes of the customers many different developments were carry out. The cost reduction in this field will lead to a marked impact. MFP will develop new devices in shorter time with applications of FPGAs and is able of adapting to market requirements easier. At present time the expenditure which is necessary for a development for one new product amount to 4 to 18 months. It is expected that about 10-20% of time can be spared by application of FPGAs. That meant a cost reduction of about 25 kECU. The size of product series decreases because of fast changing market in this time. That's why the development costs have a marked influence to product costs.

The pay-back-period is less than 2 years. With an expected product life-time of 5 years the return on investment will be around 300 - 400%.

The economic impacts:

Year	1995	1996	1997	1998	1999
Current product (kECU)					
Turnover	43	65	85	100	110
Cost	30	45	60	70	75
Profit	13	20	25	30	35
Sold number	50	75	100	120	130
Market share			0.1%	0.1%	0.1%

Improved product (kECU)					
Turnover			70	200	250
Cost			35	100	110
Profit			35	100	140
Sold number			80	230	290
Market share			0.1%	0.2%	0.25%

17. Target audience for dissemination throughout Europe

The First User wants to help small companies in the field of electronic development with the results of the FUSE project. These companies may work in the field of measurement techniques, data transmission or control devices for the manufacturing industry or any other production industry. MFP will write articles and is at the TTN's disposal for reports and seminars. Even during the current project the First User has given information to other co-operative companies of MFP. Specially information about the advantages and costs of FPGA development is interesting for small firms. One article is already written and will be published in the near future.

The application experiment is of interest for companies working in the area of

- Process engineering, companies that develop and sell measuring equipment for process automation like chemical and biological reactors.
- Industrial communication, companies that use fieldbuses within their products, with high performance requirements but moderate numbers of devices.
- Automatic control, companies that develop tooling machines, and special purpose vehicles.
- Robotics, companies that develop handling machines, autonomous and fixed robots.
- Quality assurance, companies that develop devices for quality assurance.