ASIC Based Design and Realisation of A Control Unit for A Laser Writing and Structuring System

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Abstract: This paper describes the development of an ASIC based control unit for a laser engraving-writing-structuring system. It will focus on both the developments of the ASIC based control unit for the laser system and its applications in a highly automated production environment. This work is based upon joint research and development project between the microelectronics group at KIHWV-Oostende and the Laser Applications Development group of Siemens LPT - Oostkamp, Belgium. In the context of this project a laser system is under development, which can serve as part of a (fully) automated production line. The laser system can be used for engraving, marking, writing and structuring of surfaces. The system is built around two Application Specific Integrated Circuits (ASIC). The laser and its control unit are part of a laser system unit called LSA-2, which in its turn is part of an automation unit for production systems.

Hans Manhaeve was born in Brugge, Belgium on March 11, 1963. He received the Electrical Engineering degree in Electronics from KIHWV- Oostende in 1987. After performing his military duties, he joined the KIHWV- Oostende as a staff member of the Microelectronics Department, where he is lecturing ASIC-design, testability and design for testability, testing and the use of CAD-tools. He is now working on a part-time basis towards a Ph.D in electronics, focusing on Testability and Design for Testability, at the University of Hull (UK). He is involved in several European projects such as EUROCHIP, ERASMUS, TEMPUS, ESPRIT and COPERNICUS. He is involved in several industrial research projects with Siemens, Mietec and Alcatel Bell companies. He is currently co-ordinating a COPERNICUS research project. He made active contributions to several national and international conferences and workshops such as CEEDA '91, Eurochip workshops 91-93-94, Pacific Test Workshop '92 (Canada), 8th European Design for Test Workshop '92, ASI '94, International Test Conference 1994 (ITC94-USA).

Jozef Vanneuville was born in 1946 in Nieuwpoort, Belgium. In 1970 he obtained the Electrical Engineering degree from the Katholieke Universiteit in Leuven, Belgium. He was working on laser telemeter systems for military applications at OIP-Ghent Belgium. In 1975 he joined the Katholieke Industriele Hogeschool in Oostende (KIHWV-Oostende) where he is still working as professor in microelectronics. With the support from IMEC he started the education and training programme on microelectronics (VLSI-Design) in Oostende. Since 1989 he has taken part in EUROCHIP for education and training in VLSI-design and-testing. He started a close collaboration between the department and industry for applied research on the design of VLSI-systems. He is co-ordinator of several designs for industry such as Barco, Siemens, Philips, BN-Bombardier and Alcatel Bell. Results are regularly published and presented at conferences on ASIC-Design. His main interest goes to the design of special analogue integrated circuits, using new circuit principles, and to digital signal processing systems. He is actually involved in European projects: ESPRIT, COMETT, ERASMUS, TEMPUS, COPERNICUS. He is contractor- co-ordinator of a TEMPUS-project with Czech Republic and Slovakia , called "Education and Collaboration Programme in the field of microelectronics". His interest is oriented towards training, education, research and development in Central and Eastern Europe , and towards the change, privatisation and activities of electronic industries in those countries.

Introduction

The laser unit consists of a laser source, a deflection and power control unit to control the laser beam and two dedicated ASICs, designed and processed using Eurochip and Invomec processing facilities in the context of student projects. One of these ASICs is responsible for the generation of image co-ordinates and the power and mode control of the laser source. The second ASIC controls the deflection unit, taking into account optical and surface based errors. The electronics that forms the control unit is built up around both ASICs. The control unit is designed as an intelligent peripheral card for the Siemens SIMATIC S5-115 or S5-135 series. As the S5-PLC is one of the standard systems on the European market, this means that a laser machine can be integrated easily into a production chain. The specific laser control card, also based upon EPROM loaded firmware, can

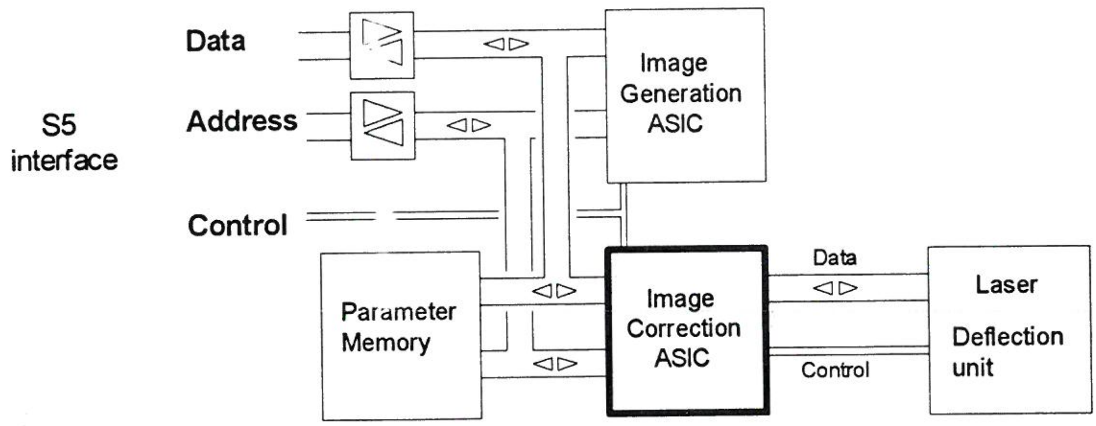

Figure 1. Control Unit Configuration

be used for various applications such as laser marking, laser structuring, laser welding and the whole range of laser applications based on the deflection of the laser beams by movable mirrors, controlled by galvano motors.

The System Configuration and Specification

The system allows the engraving or writing of text and pictures on different surfaces and the structuring of materials. A typical system configuration consists of PC with appropriate software tools, the laser, a laser beam deflection unit and a laser control unit. The data (pictures) can be scanned in, created and/ or manipulated by graphical software on a PC. These files are then converted in vector format and transferred to LSA-2, the laser control unit, which takes care of the actual writing of the image on the target surface. The writing of the images is done by controlling the laser source. This means switching the laser beam off and on at the appropriate moments in time, controlling both the power delivered by the laser source, and the laser beam deflection in function of the image and the application. The laser beam is deflected in X and Y direction by means of galvano motor controlled mirrors. This is done with an extremely high resolution of 12.5 µm for a 150 by 150 mm working area. Each XY point in the marking area is determined by two 16 bit words, representing the X and Y co-ordinates.

The generation of the necessary control signals for both the laser source and the deflection of the laser beam is done by two ASICs. The control unit is built around these two ASICs. The configuration of the control unit is depicted in Figure 1. The first ASIC, the Image Generation ASIC (IGA) can handle extremely rapid data output up to 1 MHz. The main tasks of this ASIC are data conversion, image manipulation and the generation of the associated laser control signals. The IGA receives its input data in vector format. These vectors are then processed in order to generate the image co-ordinates which the laser beam should be focused on. The IGA is also used to perform manipulations on the image such as rotating and scaling. The IGA also generates the image related laser control data in function of the programmed laser operation mode and the operation mode related parameters.

As the IGA is able to generate laser control signals for different types of lasers and different laser operation modes, the control unit can be tailored towards a broad range of laser applications. Furthermore, the IGA contains an adaptive power control unit to control the power released by the laser source. This allows to use the system also for structuring applications where the control of the laser power is the key factor in avoiding over- or underexposure.

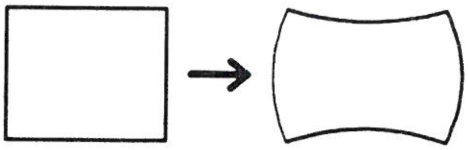

Figure 2. Cushion Distortion

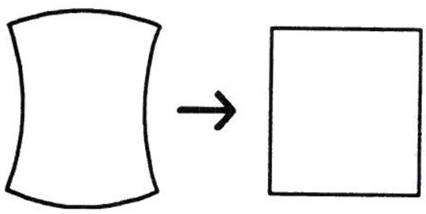

Figure 3. Predistortion

The (picture) co-ordinates generated by the IGA are then modified by the Image Correction ASIC (ICA) before they are used to drive the deflection unit. The main task of the ICA is to carry out co-ordinate transformations that are depending on the shape of the writing surface, the deflection of the mirrors and the optical distortion introduced by the focusing lens. If no correction were performed, then due to the optics and the deflection system, cushion distortion would occur as shown in Figure 2. This is solved by performing a predistortion on the actual image that is function of the optical and mechanical inaccuracies of the focusing system and the surface parameters. This is illustrated in Figure 3. This approach allows to write on any kind of surface (e.g. cables) without any image distortion.

The ASIC based control unit is capable of controlling the laser beam deflection with a speed up to 12.5 m/s and with a resolution of 12.5 µm, in a working field of 15 by 15 cm. Furthermore distortion can be corrected up to ± 12.5 µm. Image co-ordinates can be generated at a frequency of 1 MHz, which is about 25 times faster than today's rapid microprocessors, which are capable of issuing co-ordinate pairs at a maximum frequency of 40 KHz. This corresponds to a writing speed of only 500 mm/s. For economical laser marking on polymers, writing speeds of 2000 to 3000 mm/s are required. These speed requirements are easily fulfilled by the ASIC based control unit.

For structuring applications, speeds of 500 mm/s are usual. Dimensions of 75 µm for the width of connections and distances between, can be reached.

The control unit has a S5 interface, which allows an easy integration of the system into a production environment.

ASIC Design and Specifications

The ASIC developments were the results of an in-depth evaluation performed at the beginning of the project. The main goal of the two ASICs is to execute a number of time critical functions. Therefore a number of speed influencing algorithms, which would be too slow if executed in software, were implemented in dedicated hardware to speed up the system. The integrated algorithms were at first implemented in software for evaluation, but the overall performance of the system was then too slow. Using an implementation technique adapted to the requirements of the system made it possible to develop a system that performs much better than the previous fully software based design. This approach made it possible to develop a laser based writing system, which is not only as fast as other printing techniques (or even faster) but also offers extra possibilities such as a continuous changing or updating of the image. A drawback of the system is however that a hardware based solution is not as flexible as a software based one. A solution under evaluation is the use of programmable building blocks such as FPGA's, to increase the flexibility of the system.

The work done at KIHWV in the context of this project so far consists of four main parts. First the Image Correction ASIC was designed. The main task of this ASIC is to execute the correction algorithm based upon a predistortion technique. The functions that describe the predistortion require complex mathematical operations. They cannot be realised easily just using hardware. To solve this problem a linear interpolation technique was used, related to a proper division of the working area as illustrated in Figure 4.

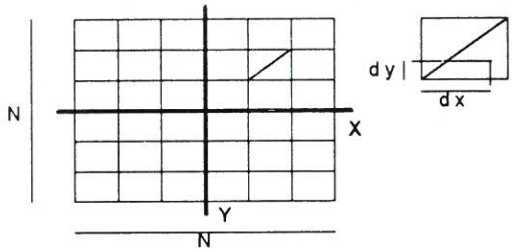

Figure 4. Working Area Division

The working area is therefore divided into N by N squares. Each square is divided into two triangles and is characterised by an M by M grid division. Linear interpolation with appropriate coefficients is applied for each of those triangles. Therefore, based upon the input image co-ordinates, predistortion coefficients related to the proper triangle are read from the parameter memory and new image co-ordinates are calculated on-line in function of the position of the laser spot. Care is also taken of keeping the laser spot within the working area of the deflection unit. This is done by means of a clipping function to avoid damage of the deflection unit.

The ICA has a pipeline structure and is capable of generating output co-ordinates at a speed of 750 ns per corrected co-ordinate pair. Input data are read in via a microprocessor interface, similar to the one contained in memories, which allows a direct microprocessor connection for data transfer. Correction calculations start when a full co-ordinate pair (both X and Y value) was read in. At the output, the ICA has a dedicated interface that allows direct communication with the deflection unit. The ICA was designed using the Silvar-Lisco design environment, based upon the MIETEC 2μ CMOS standard cell library. Simulations and test pattern generation were done using System-HILO. The chip occupies an area of 32 mm^2 and is contained in a 100 pin PGA package.

In a second step, a first version of the Image Generation ASIC was developed, targeting for laser writing applications. The IGA converts vector images to input data suitable for the ICA and it generates the control signals for the laser operation. The IGA converts vector data to absolute co-ordinates and in the meantime it allows image manipulations such as rotating and scaling based on a number of programmable parameters. Furthermore, the IGA generates the proper control signals for driving the laser, based upon the programmed laser operation mode and the performed image manipulations. The IGA can drive various types of lasers in various working modes, such as continuous mode, pulse mode, Q-switch mode, etc.

During the next step in the development of the system, the IGA was re-designed to allow an adaptive power control of the laser, and the necessary interface logic to the laser unit was developed. This expanded the target area of the system with laser structuring as an additional application. A typical application of this system is the illumination of PCB boards and to prevent over- and underexposure. Therefore the amount of energy reaching the PCB surface is controlled. An acousto- optic modulator (Bragg cell) makes it possible to deflect the laser beam, which is then led through the diaphragm of the optical unit and positioned by mirrors. The control signal for the modulator is generated by the IGA, this is done depending on the velocity of the positioning mirrors. In fact the IGA generates a number of pulses. Each pulse means a spot of light on the writing surface and thus allows to draw lines and pictures. However to avoid exposure problems, the amount of energy on the writing surface must be kept constant, so the number of pulses has to be adapted in function of the velocity of the deflection mirrors which control the position of the laser spot. To make this possible an interface circuit has been developed, which extracts out of the velocity information the proper feedback information required for the adaptive pulse generation by the IGA.

Current research is focusing on increasing the flexibility of the system and expanding the application domain by writing on moving objects. A VHDL based re-design is needed as the IGA is on-going to incorporate this functionality as well. To increase the flexibility of the system, the use of complex programmable building blocks to the system is under evaluation. Another research topic is the use of the laser system for high precision soldering applications. The current version of the IGA was designed using the Mentor Graphics design environment and the MIETEC 2μ CMOS standard cell library. The circuit occupies an area of 35 mm^2 and is also contained in a 100 pin PGA package.

System Application Areas

Target applications for LSA-2 are those where the laser can be used to engrave or write on different kinds of surfaces, on different kinds of materials and where the data to be written may change from object to object and from image to image. Another target area of the laser system is the use of a laser beam for the structuring of materials.

As an example of the first application area a production line for keyboards may be considered. A lot of clients for computer keyboards often impose their own specific requirements whereby they wish to have their own standard characters and symbols on certain keys of the keyboard. This results in a wide range of variants at the production stage. Furthermore the identification on the key must not fade or disappear after long-term use. These problems can be solved by a laser marking station at the end of the production line. First the keyboards are fully assembled with standard 'naked' keys and secondly the laser writing system is used to write data on each key of the keyboard. The host computer of the line informs the PC of the laser marking machine about the required variant and the instructions are then passed on to the laser and the table control system. An accurately focused pulsed Nd-YAG laser marks then the required symbol on the key at a speed of 5000 mm/s. The size of the marking field is 15 by 15 cm without any need for table movement. The laser deflection system is combined with the table movement system to ensure that all sizes of keyboards can be marked. The ICA and its implemented correction algorithm allow not only to write on top of the keys, taking into account already the shape of the key surface, but make it also possible to write on the key sides during the same writing session, without any need for table movements or positioning. Coloured writing is also possible by making use of a low power CO2 laser and a colour film. White symbols on a black background are also possible. This approach allows a maximum of automation and standardisation of the production process and a maximum of flexibility, as the data to be written may vary from keyboard to keyboard.

Other writing-engraving applications are those where a continuous updating of the data is needed. As an example the writing of a logo together with an identification number, that is updated from product to product, can be mentioned. One main advantage of laser marking is also that the data cannot be removed without visible damage to the product on which the data were written. The current version of the laser control unit also allows marking on moving objects. An application example is the marking of cables, where the marking needs be performed at regular intervals without the need to stop the moving cable. To avoid data deformation and not equidistant markings, the laser marking system is able to adapt to the speed of the moving object.

An example of structuring applications is the use of the laser unit to define the conducting areas on PCB boards and also on three dimensional surfaces in the development of PCB structures adapted to the available room and space. The laser control unit has already been proven to be successful in the development of MID Technology based devices. MIDs are Moulded Interconnection Devices, which are three dimensional plastic shapes provided with one or more metal interconnection layers. MIDs serve both as housing for the circuit and as carrier for the circuit components. The use of MIDs allows the development of cheap and environment friendly electronic devices that are fully adaptable to the available room and space.

The MID technology was developed and patented by Siemens LPT and consisted of four basic steps. One of them is the structuring phase where the laser is used to define the shape of the three dimensional interconnection structures, without any need for special movements of the object, on which the structures need be defined. No special masks are needed for this. The laser system uses the software masks developed by the CAD layout system. This approach allows fast prototyping and design modification. Structuring dimensions up to 70 μm can be reached with structuring speeds up to 500 mm/s. These fine interconnection structures allow a direct integration of SMD components or naked chips or micromechanical devices with a MID. A key factor in this success story is a careful control of the laser power during structuring, in function of the movement speed of the laser beam and the shape of the surface. This is required to maintain the quality of the interconnection structures and to avoid over- and underexposure.

Each of the above mentioned application areas makes its own demands on the control system of the laser unit. However the ASICs used in the control part of the system were designed by taking into account the compliance of the system with its application requirements.

Conclusions

The use of ASICs for the development of the laser control unit made it possible to develop a laser based writing-marking system that can be used for various types of applications, where flexibility, quality and speed are important. An important factor for the use of ASICs, apart from the speed advantages, is knowledge security. Using Multi Project Chip (MPC) processing facilities as offered by EUROCHIP, makes low volume production of ASICs economically feasible. The system is also capable of writing on moving objects. The system has already proven its efficiency in various application areas.

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