Developing an Optical Spectrum Analyzer

Realizing a complex embedded system with student groups

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Abstract— **Within the curriculum of the Bachelor Electrical Engineering there are obligatory lab experiments for electrical measurement. In this lab ready-made standard experiments with defined results are carried out by students. As an alternative to these standard experiments individual development projects for interested students are offered. In one series of projects an Optical Spectrum Analyzer (OSA) is going to be realized by students. The complete opto-mechanical hardware was sponsored by a measurement company and groups of students develop additional components to complete the OSA. Currently all important electronic subsystems of the OSA are developed and tested. These are integrated into the whole system and a software environment for controlling the whole system is built. The high learning success of the student groups and the consistently positive feedback from the students is encouraging. Currently this type of project is expanded to other topics.**

Analog circuits; Educational technology; Electronics engineering education; Optical spectroscopy

I. INTRODUCTION

In the study course Bachelor of Electrical Engineering there are the lectures Electrical Measurement part 1 (in the second semester) and part 2 (in the fourth semester) with the laboratory courses Electrical Measurement part 1 (in the third semester) and part 2 (in the fourth semester) where groups of usually three to four students carry out experiments for gaining practical experience in electrical measurement and analog electronics. During the lab course 1 some basic skills like handling measurement instruments and doing elementary experiments are taught. In the second lab course more advanced experiments are done to increase the practical electric measurement skills of the students.

Some years ago skilled and motivated students asked for projects instead of the standard lab experiments to gain industry relevant experience. Due to this demand the project “OSA development” was created where student groups develop a new electronic and software environment around an existing opto-mechanical OSA hardware block. This project takes a whole semester with an estimated work load of about 30-40 hours for each student. These projects are voluntary instead of the standard lab experiments. This leads to a high intrinsic motivation of the student groups [1].

The opto-mechanical hardware for the Optical Spectrum Analyzer and a laser source were sponsored by JDSU. The I/O-Board for connecting the OSA to a PC was sponsored by National Instruments.

II. SCOPE OF PROJECT

In the German Universities of Applied Science the education of engineers connects theoretical knowledge with industry relevant practical experience. In Industry most projects contain theoretical and practical parts which are carried out within a team. A technical framework is already given before the start of the project and new parts or functions which interact with the framework have to be developed.

Here the students train this industry relevant type of project and get practical engineering skills which are essential for their professional life. They see the difference between theoretical knowledge and practical work. For many of the students it is their first practical hardware development within a team and they learn how to divide a project into different work packages, carry them out and combine them to a complex device.

The technical basis for this professional training is the development of a working OSA which has challenging electronic building blocks. The goal is to finish an OSA with working hard- and software to use it for lab education.

III. PROJECT ORGANIZATION AND PHASES

After the student group received their project specification and an introduction lesson into the functionality of an Optical Spectrum Analyzer the group is requested to organize the project by itself. The adviser of the lab course gives hints if technical problems arise which cannot be solved by the group alone. If problems between the students arise mediation can also be required.

The project scheme is usually chosen by the students as follows:

- They start to become familiar with the tasks and with the given hardware.
- The students separate the project into parts and distribute the tasks among the team members.
- They develop electronic circuits, calculate and simulate the performance. With feedback from the adviser they optimize the performance of the circuit.
- The students look for appropriate electronic parts at the manufacturers’ web sites and order samples.

- With these parts they build a first test circuit and verify the correct operation. Problems are found and fixed and sometimes the circuit is further optimized.
- From the experience of the first circuit the students draw a layout for an etched printed circuit board (PCB). It is made, assembled and tested. The parameters are measured and compared with theory.
- After the hardware works the students have to present their results to the other lab groups. They usually prepare a PowerPoint presentation where the highlights of the project are depicted.

During the whole project the students must document the project work and their results. This documentation is stored as a basis for following project groups.

IV. GIVEN OPTO-MECHANICAL HARDWARE

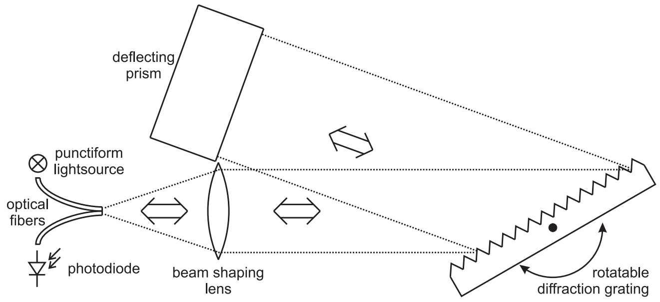

Figure 1. Optical setup of OSA

The given opto-mechanical hardware is from a JDSU OSA-201 [2][3]. The principle of the optical setup is shown in figure 1. It is a single monochromator in littman configuration where the diffraction grating is passed twice for high spectral resolution. The grating is rotated using a scanner motor with flexure bearings. Light is coupled via single mode fibers into the OSA. At the output side photodiodes convert the optical output power into a proportional electric current. A wavelength reference (which is not shown in fig. 1) with an infrared light emitting diode (LED) and an acetylene gas cell is integrated which can be used for wavelength calibration during operation. The wavelength range of the OSA is from 1250nm to 1650nm which is limited by the maximum angle of the scanner motor. Figure 2 shows a photo of the opto-mechanical hardware.

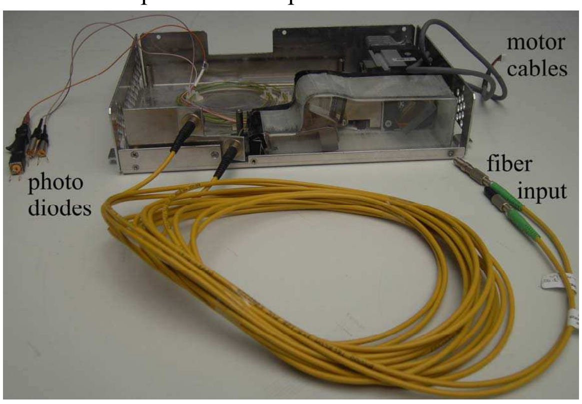

Figure 2. Opto-mechanical hardware of OSA

V. REACHED PROJECT STATUS

Up to now the main building blocks of the OSA electronics are developed and tested. The system is integrated and a first version of the control software is written. The following projects of the OSA development are realized:

A. *Summer semester 2008*

1) *Linear transimpedance amplifier*

This was the first test project to see if the new concept for the electrical measurement lab works. One group of two students had to build a linear transimpedance amplifier to convert the photodiode current into a proportional voltage. After designing the electronics and selecting the components they soldered a test circuit on a grid-style PCB and verified the correct function. In a second iteration they made a layout, fabricated an etched PCB and tested the correct function of the circuit. In the third iteration they added a low pass filter for improved noise performance, fabricated a new PCB and documented the results. In figure 3 the last version of the transimpedance amplifier is shown. The left operational amplifier converts the photodiode current coming through the red cable into a voltage. With the right operational amplifier an active low pass filter is realized.

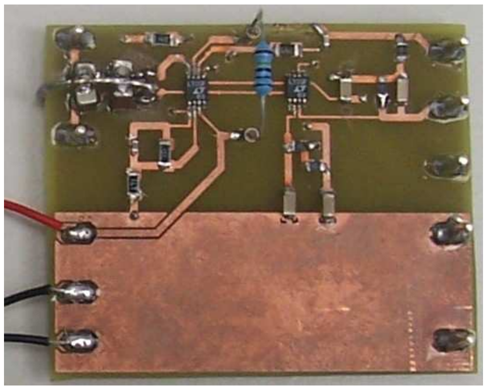

Figure 3. PCB circuit of linear transimpedance amplifier

B. *Winter semester 2008/09*

1) *Logarithmic transimpedance amplifier*

The logarithmic transimpedance amplifier converts the photo diode current into a logarithmic voltage. This has two advantages compared with a linear amplifier. First the current range of many decades is measurable with one amplifier and second the output voltage can be directly displayed in a logarithmic scale which is usual for optical telecommunication applications.

A group of four students developed this project. They first became familiar with the theory of the concept and then calculated the properties of the circuit. A rail to rail operational amplifier with low noise was selected from a vendor's homepage and the calculated circuit was simulated. After drawing a layout, building a PCB and assembling the parts they measured the response curve of the amplifier (fig. 4). The photo current is on the logarithmic abscissa and the output voltage is on the ordinate. The circuit shows a good logarithmic behavior which is in line with theory.

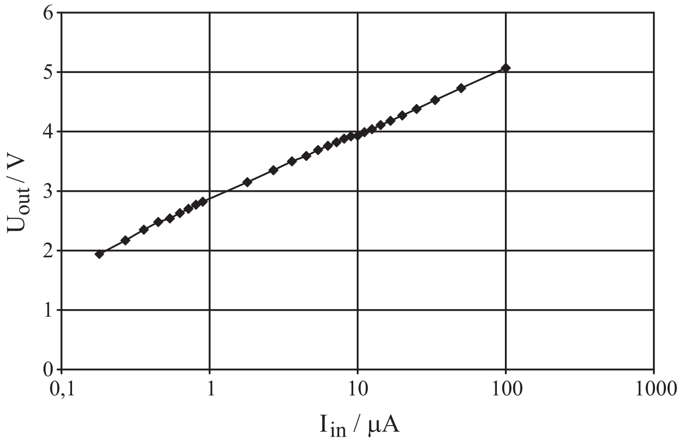

Figure 4. Response curve of logarithmic transimpedance amplifier

2) Motor driver using a microcontroller

One group had the task to develop a drive electronic for the motor. The intention from the supervisor was the development of a linear driver with an H-bridge. This was not clearly enough communicated to the student group so they decided to use a microcontroller and switching transistors for powering the motor. The controller was programmed with a constant velocity ramp and depending on the motor position the pulse width of the switch transistors was changed. This project succeeded but it was not possible to integrate this circuit into the system. Therefore it was decided to repeat this development during the next semester with more precise specifications.

3) Driver electronics for wavelength reference LED

The infrared LED for wavelength referencing must be supplied with a constant current. This current is controlled using an integrated monitor photodiode which detects the output power of the LED. A current source was developed by the student group which supplies a constant current independent of the LED and environmental conditions. A test board was developed using a blue LED where the functions can directly be seen. A current limiter with a limit of 200mA was implemented to protect the LED from destruction. A PCB with the final circuit was built and verified.

C. Summer semester 2009

1) Angle sensor electronics

In the scanner motor a capacitive angle sensor is integrated. This sensor is driven by an external DC-voltage and outputs two currents with the angle proportional to the difference of these currents. A group of four students realized this demanding project with their main scope on a low noise circuit. After learning the noise theory, designing the circuit and selecting the components they calculated the amplifier noise. They saw that this was much lower than the noise from the position sensor and so they built up this amplifier.

Figure 5 shows the block diagram of the angle sensor. The output currents of the angle sensor are transformed into voltages by transimpedance amplifiers. These values are added and the sum acts as a control input for the angle sensor supply. The current difference is the output signal of the sensor electronics and proportional to the scanner drive angle.

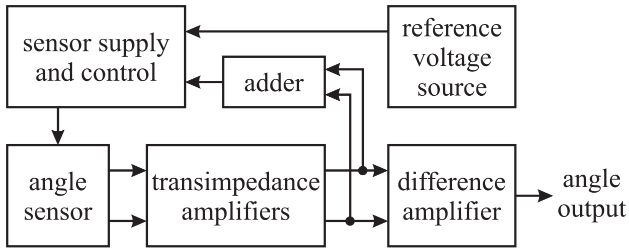

Figure 5. Block diagram of position sensor

2) Linear motor driver using an H-bridge

The project for building a motor driver electronic was again offered. In the tighter project specifications an analog input voltage with a proportional output voltage was demanded. The student group chose an operational pre-amplifier which transforms the range of the input voltage to an appropriate voltage for the bipolar H-bridge transistors. With a feedback loop from the output of the H-bridge to the input of the pre-amplifier the distortions around the zero voltage output of the H-bridge are compensated.

Together with the student group developing the angle sensor they built up a test set up with a scanner drive and their electronics to show the function of the whole motor drive and position sensor system.

D. Winter semester 2009/10

1) Connecting the hardware parts and creating a control software using LABVIEW

The opto-mechanical OSA hardware was connected to the motor driver, the position sensor and the logarithmic transimpedance amplifier. These parts were connected to a PC using an interface card with analog/digital and digital/analog converters. The student group used LABVIEW to set the driving voltage for the motor and read out the voltage of the logarithmic transimpedance amplifier. By stepping the motor voltage over the whole range while reading out the amplifier values an uncalibrated optical spectrum was constructed and shown on the screen. Two fabry-perot laser diodes with 1310nm and 1550nm wavelengths were coupled into the OSA input fiber. Figure 6 shows this first measured spectrum with the two lasers in it.

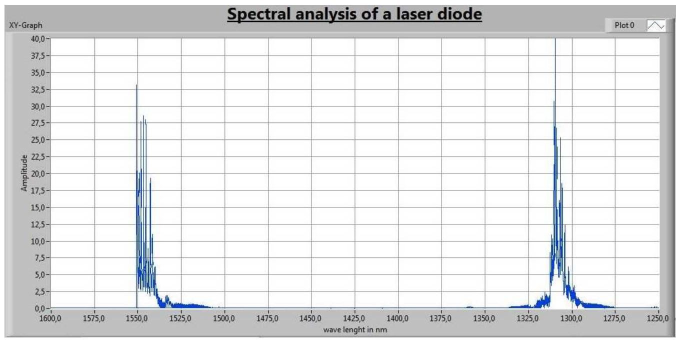

Figure 6. First measured spectrum with OSA

VI. FEEDBACK FROM STUDENTS

After each project completion systematic feedback from all students was gathered. Here the main points which were highlighted by the students:

- Summer semester 2008, transimpedance amplifier: The project was very interesting because of the different tasks. It was very good to see the results and the success. A better explanation should be made how parts are sampled and PCBs are ordered. At the beginning the work load and the division of the project among the students were unclear.
- Winter semester 2008/09, LED driver: It is better than lab courses with fixed experiments because of a higher motivation, learning from own mistakes, having a free time schedule.
- Winter semester 2008/09, motor driver: The learning effect was very high but the project was also very time-consuming. The group work was a lot of fun. It was better than the standard lab experiments.
- Winter semester 2008/09, transimpedance amplifier: Positive was the own development of an electronic circuit, independent work made fun. The main disadvantage was the high work load.
- Summer semester 2009, position sensor: The advantages were the free time schedule and the creative work. The project matched with the theoretical lectures during the fourth semester. The project was an instructional experience and a good alternative the normal lab course.
- Summer semester 2009, motor driver: The expenditure of time was higher than expected. The development of the electronic circuit was challenging but funny.

VII. CONCLUSION

From advisers' side we saw that during these projects the students got a higher knowledge increase than with the prepared standard experiments. This was also confirmed by the written test at the end of the lab course. The grades of the project students were better than the average course value.

The students already had a lecture of analog electronics but for many them this project was the first practical experience with the design and assembly of an electronic circuit. At the start of the project many students had great difficulties to transfer the theoretical knowledge into practice. During the project they learned how to build a working electronic board with all practical problems.

The groups had to organize itself. They divided the individual tasks among the project members and combined the parts to one solution. At the beginning this was challenging because no adviser gave them a detailed instruction how to schedule the work. During the project the students formed a team where one could rely on the others.

At the end of the project the students had to present the work results in front of the advisers and the other students. This was a challenge for the introverted ones but in professional life it is inevitable to present the work in an appropriate way.

We also saw some risks during the projects. The way how to solve the project was open, so some groups found impractical or wrong solutions. If the students came during the project work to a dead end they spent a lot of time without finding the further way. The consultation of the adviser was very late so the groups lost a lot of time or presented an unrealistic solution. It is important from the advisers' side to clearly tell that consultation and discussion does not lead to grade degradation. It is also important to ask for one or two interim reports to see how the project is going on and how much time is already spent.

During the first semesters the project specifications were short to give the students maximum freedom for developing own solutions. This was considered negative from some groups because students were uncertain which technical solution they should choose. Therefore in the last semesters the specifications were detailed and the problem disappeared.

VIII. PLANNED WORK AND OUTLOOK

After the winter semester 2009/10 semester we have finished the first version of a working OSA system. During the next projects two main work directions are planned.

During integrating the OSA some problems with the actual transimpedance amplifiers arose concerning speed and value range. Therefore it is planned to build new amplifiers with improved characteristics. The second goal is the improvement of the measurement algorithms with filtering the position and optical power values. A wavelength calibration algorithm should be implemented and tested. It would be very interesting to calibrate the self-built OSA and compare it to a commercial one.

Due to the high success of this type of project we offer in the meantime other topics. Additionally we started the work on a wireless weather station which is modularly set up and therefore expandable to any functional range.

In the middle future we intend to switch the whole lab course from fixed experiments to project work to provide an optimal education for our engineers.

ACKNOWLEDGMENTS

First of all I want to thank all the highly motivated and competent students who carried out the project work. They made this new type of lab experiments a success. I also thank my colleagues for the fruitful discussions when creating and optimizing this type of project work.

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