A Team Centered, Project Oriented Approach in Analog Integrated Circuits

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Abstract
This paper describes an end-of-semester day-long required project used as a capstone to a junior electrical engineering technology course in Analog Integrated Circuits Applications. The motivation for the project is presented in the Introduction. The Project Description explains both the problem presented to the students and the implementation constraints. The Evaluation section has three parts; the subjective evaluation of the project by the students, the subjective evaluation of the project by the course instructors, and the objective results, including the students' performance evaluation, and a comparison of the students' overall course performance as compared with previous semesters which did not include a project. Finally, continuing trends in the application of teaming are presented.

Introduction

During the summer of 1992 Motorola presented Purdue University with a Total Quality Management (TQM) Challenge. The objective of the challenge was to integrate the principles of Total Quality Management into the university. This included both teaching *about* TQM, and teaching *with* TQM (using TQM principles and techniques to improve the quality of the instructional process). One hundred key faculty and administrators from the schools of Business, Engineering, and Technology were invited to a week-long, twelve-hour-a-day seminar on TQM. Each day began with success stories, followed by specific instruction on the central principles of TQM. Small group, facilitated workshops were provided in the afternoon to allow cross-discipline teams to apply the material presented in the morning sessions. In the evening, these same teams met to plan how the day's techniques could be implemented in the team members' own courses.

A key element in this implementation of Total Quality Management is the use of empowered teams. Providing workers (i.e. students) the responsibility and the resources to accomplish their assigned task allows them to take ownership of the problem, and to bring to bear all of their combined energies and abilities. Together, the team is stronger than the sum of each of the individuals. This TQM technique was applied to a junior course on Analog Integrated Circuits Applications taught by the Electrical Engineering Technology Department of Purdue University's West Lafayette campus.

Project Description and Implementation

As a capstone to the Analog Integrated Circuits Applications course, the students were assigned to five person teams during the last quarter of the semester. Teams were configured so that each team had members from all grade categories within the course. Several exercises were assigned which required a team solution, including a take-home question on one of the major course exams (counted 25% of that exam). Professor Cynthia Orczyk, from the Department of Organizational Leadership and Supervision provided a guest lecture on the mechanics of making teams work.

Class and lab were canceled the last week of the semester. In their place was a ten hour team design project. The students and the course instructors met from 7:30 am until 5:30 pm the Saturday proceeding the last scheduled week of the semester. The project was described at that time. Each team was to design, build, demonstrate, and document a digitally controlled frequency synthesizer. The problem was so defined as to require key elements from each block of the course (see figure 1). Otherwise, the problem was largely left to the abilities, and imagination of the team.

EET 368
Analog Integrated Circuits
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End-of-Semester Team Project

DESIGN

Design a digitally controlled sine wave generator to meet or exceed the following specifications. each of these parameters must be digitally set.

frequency	20Hz (or less) to 20kHz (or more)
amplitude	50mVrms(or less) to 2Vrms(or more)
offset	-5V(or more negative) to +5V(or more positive)

RESOURCES

Your team may use the following items provided by the EET department.

1. TTL clock at any one fixed frequency
2. 25.5Vrms CT transformer connected to 115Vrms primary power
3. 5V @ 2A regulated DC voltage
4. two AD 7524 digital-to-analog converters
5. one MF6 switched capacitor low pass filter
6. one MF8 switched capacitor bandpass filter

You may "simulate" a digital level with a DIP switch or jumper to +5V or 0V and an analog switch or relay with a jumper. You may use any other parts and hardware your team members have EXCEPT hardware and software developed for EET 490/1, Senior Design. You may use components obtained for these courses.

EVALUATION

The 10 points of your course grade will be distributed as indicated below. Performance of each area is worth 70%, documentation of that block is worth 30%.

power supply	1.5pt	powers all other blocks
frequency generator	2.0pt	provides a sine wave
frequency adjustment	3.0pt	across 20Hz to 20kHz
amplitude adjustment	2.0pt	across 50mV to 2V
offset adjustment	1.5pt	across -5V to +5V

EXTRA CREDIT

One point extra credit will be awarded to the team for microprocessor or personal computer command of frequency, one point for microprocessor or PC command of amplitude or offset, and one point for a friendly (e.g. key pad entry, LCD display) user interface.

COMPETITION

Each team's project will be evaluated to confirm that it meets the criteria above. Additionally, the unit will be commanded to a specific frequency, amplitude, and offset. The rms sum of errors will be determined as indicated below.

$$error = \frac{desired - actual}{desired} \times 100 \ \%$$

$$error_{total} = \sqrt{error_{freq}^2 + error_{amplitude}^2 + error_{offset}^2}$$

The team with the lowest total error will be awarded 5 additional points, added to their overall course grade. The second place team will receive 3 points and the third place team will have 1 point added to their overall course grade.

RECOMMENDED PROCEDURES

Below are suggested steps that your team may wish to follow:

1. Brainstorm to obtain a list of techniques to be used to produce the signal.
2. Discuss the advantages and disadvantages of each technique.
3. Select the technique to be used.
4. Draw a detailed block diagram.
5. Define verbally the function of each block.
6. Numerically define all signals into and out of each block. Do not overlook the power supply voltages and all digital control signals (especially if you hope to add a microprocessor or personal computer.)
7. Divide the work among team members.
8. Agree upon the schedule for the remainder of the day.
9. Brief Professor Jacob on your plan (steps 3 through 8).
10. Implement your plan.
    a. Develop and test each block separately.
    b. Integrate blocks, one at a time.
    c. Verify performance.

    During this step, team members should re-convene to report progress every hour.
11. At 3:00 one team member must be available to demonstrate the project to the faculty. the remaining team members will document the design and performance of the synthesizer.

DOCUMENTATION

A package should include the following:

Detailed block diagram.
Description of the signal synthesizer technique selected.
For each block:
- schematic.
- performance test procedure.
- performance data.

Figure 1: End-of-Semester Team Project Initial Explanation

Brainstorming

All seven of the EET department labs were opened. All teams began by meeting to brain storm, select a design structure, and determine an implementation plan. Among the thirteen teams there was a wide variation in the effectiveness of these initial meetings. Some were highly interactive, with spirited participation of all members and several divergent designs discussed. Other meetings were dominated by one person, with other team members adding their differing opinions to the dominant team member's suggestions. These teams had little discussion, and were finished with their meeting quickly. But the resulting designs was usually flawed, with the weaknesses not surfacing until the integration phase, too late to correct. Each team briefed the major course professor individually on their overall design, and their implementation plans. Only if it was obvious that the design would not work, at all, were the plans rejected. Otherwise, concerns were voiced, and the teams allowed to address those weakness, or not, as they chose. This portion of the day took some teams only one half of an hour, while other teams were repeatedly encouraged to end their planning after one and a half hours.

Block Implementation

The individual block implementation phase followed. All teams divided the tasks among their members, and all students were actively involved. Of the over sixty students, none were watchers or passive data recorders (as is too often the case in more traditionally structured lab exercises). However, as is to be expected, the academically stronger students completed their blocks quickly, and then assisted (or took over from) the weaker students. An unspoken target of the course instructors was that each team have all of their blocks functional, separately, by noon. Over half of the teams reached this goal. These were then sent to lunch when they informally satisfied one of the course instructors that their blocks functioned individually. At this point, the major course professor provided direction to the lagging teams in the form of probing questions targeted at the weak points in the deficient designs, or implementations. Of the thirteen teams, two had worked themselves into a blind alley, and required some direct advise.

Integration

The widest variation in success occurred during the integration phase. Most team members had constructed their blocks on individual proto-boards. The more advanced teams had all blocks functional, and accomplished integration by adding one well documented block at a time to the growing project. They then added computer control, tweaked their software and verified specification compliance. Four of the thirteen teams were completely successful. On the other extreme, those teams that were unsuccessful were plagued by one or more blocks which never functioned. For them, by early afternoon, frustration and anxiety set in. These teams degenerated to groups of watchers while the one or two dominant members tried to patch thing up. Faculty intervened only to keep tension bearable, and tempers under control.

Determination

At 3:00 pm, a halt was called. Each team selected one or two members to demonstrate their project to the faculty. The rest of the team left to complete the documentation and to write the project report. Within a lab, the students were told to apply power to their project. Each team's demonstrator was ask to accomplish the following adjustments, using only digital control bits (i.e. no potentiometers or other components could be adjusted.)

- maximum frequency
- minimum frequency
- maximum amplitude
- minimum amplitude
- most positive DC offset
- most negative DC offset
- output at 1kHz, 1Vrms, -1VDC

A course instructor recorded the project's performance at each of the extremes, and the percent error of frequency, amplitude, and offset, at the 1kHz,1Vrms, -1VDC check point. The tabulated results are shown in Table 1. This procedure was repeated in each of the labs, until all projects were evaluated.

	1	2	3	4	5	6	7	8	9	10	11	12	13
power	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
f max (Hz)	14k	20k		14k		27k	8k	20k	2k	20k	400	300	20k
f min (Hz)		700		22		2	500	20	20	40	4	38	20
vmax(Vrms)	2.0	2.0		2.9	2.0	2.2	2.0	2.0	2.3	2.5	2.0	2.0	2.0
vmin (Vrms)	0.05	0.7		0.02	0.3	0.02	0.05	0.05		2.5	0.05	0.7	0.05
DC max (V)	0	5.0		5.0	1.2	5.0	5.0	5.0	2.4	5.0	5.0	5.0	5.0
DC min (V)	0	-5.0		-5.0	0.5	-5.2	-5.0	-5.0	2.4	1.6	4.9	-5.0	-5.0
1 kHz (Hz)		714		4k		1.1k		945	1.8k		416	307	1.0k
% error (%)		28		300		11		6	-75		58	69	0
1 Vrms (V)		1.71		1.16		1.02		1.07	2.34		1.02	6.1	1.00
% error (%)		71		16		2		7	134		2	510	0
-1VDC (V)		-1.5		-0.3		-1.1		-0.8	2.4		4.9	-1.7	-1.0
% error (%)		46		73		9		26	340		590	65	0
tot error (%)		89		309		14		27	373		590	519	0

Table 1: Evaluation Worksheet

<u>Grading</u>

The course instructors then met to review the teams' performances and to assign course points. These total point awards are listed in Table 2. In reviewing this data, keep in mind that each point on this project is one point on the student's <u>overall</u> course grade. The project was weighted as 10% (10 points) of the total course grade. Any points over 10 were extra credit. Course grade breaks were every 10%,(A:90-100 B:80-89 C:70-79 D:60-69 F: <60) so a good performance on this project could change a student's course grade by over a letter.

	max	1	2	3	4	5	6	7	8	9	10	11	12	13
Performance	7	5.6	6.1	4.2	6.7	6.3	7.0	6.0	7.0	3.9	4.8	5.3	5.0	7.0
Computer	3*	0	3.0	0	0	0	3.0	0	2.0	0	0	1.0	0	0
Competition	5*	0	0	0	0	0	3.0	0	3.0	0	0	0	0	5.0
Report	3	2.7	2.1	2.6	2.7	2.7	2.7	2.4	3.0	2.3	2.7	2.6	2.7	2.7
Total	10	8.3	11.2	6.8	9.4	9.0	15.7	8.4	15.0	6.2	7.5	8.9	7.7	14.7

* Extra credit

Table 2: Points Awarded

A closing meeting was held at 5:00 pm. The team reports were submitted. Team points were awarded (i.e. their course grade), and an opinion survey taken. The opinion survey is shown in Figure 2. The number in the brackets to the left of each question is the average score for that question based on the responses of all thirteen teams.

Indicate your level of agreement to the statements below concerning the end-of-semester project for EET 368. Fill-in the appropriate circle on the answer sheet:

1 = strongly disagree ... 3 = undecided ... 5 = strongly agree

[4.2] 1. The subject matter of the project is appropriate (i.e. the project reflects what I learned, or should have learned in the course).

[3.6] 2. The expectations (specifications) were appropriate.

[4.1] 3. The problem was clearly defined.

[2.7]	4. There was enough time to complete the problem.
[3.5]	5. Adequate resources were provided.
[2.9]	6. The format (i.e. all day Saturday at the end of the semester) is appropriate.
[3.1]	7. The grading scheme is fair.
[2.8]	8. The weighting of the project in the total course grade is appropriate.
Working as a team was	
[2.7]	9. hard.
[3.8]	10. worthwhile
[3.8]	11. necessary to successfully solve the problem.
My team functioned well	
[3.9]	12. overall.
[3.7]	13. during the planning and design.
[3.9]	14. during the individual block implementation.
[3.2]	15. during the integration phase.
[3.8]	16. to produce the documentation.
[4.0]	17. Everyone on my team did their fair share.
Overall, this end-of-semester team project was	
[3.6]	18.a good idea.
[3.0]	19. fun.
[3.8]	20.frustrating.
[3.5]	21.a real learning experience.
[3.5]	22. worth doing again in this course.
[3.4]	23. worth doing in other EET courses.

Figure 2: End-of-Semester Project Survey

Project's Effectiveness

Students Subjective

The survey administered at the close of the day, as stated, is shown in Figure 2. Keep in mind as you review the scores that the tool was administered at the end of a very long day, immediately after several teams had experienced a significant amount of frustration, and before the final impact on their course grades was determined.

The first section of the survey reviews the administration of the project. In summary, students felt that the project was appropriate and fairly graded. However, most felt that the single day format did not allow enough time. The course professors believe that the low score on item 8 (weighting of the project in the total course grade) was caused by concerns from teams which had performed poorly.

Students received working in a team well. They felt that it was not difficult to do, and was both necessary and worthwhile. They also felt that their team functioned well as a single unit working toward a common goal.

The summary section of the survey indicates that the students found the project enjoyable, and a worthwhile part of the course.

Faculty Subjective

The major objective of the project was to provide a summary of the course topics in a realistic application. That was most certainly accomplished. A second goal was to have the students participate in team-centered problem solving. Each group did, indeed, make some efforts at team work. With one exception, the groups which scored the highest seemed to work most smoothly together. The efforts of the other successful group was dictated by a single member, while other group members assisted, or stayed out of the dominant member's way as they completed the project largely on thier own.

Two characteristics seemed to be common to the groups which scored poorly. There was no clear leader and poor decisions were made. Faulty decision making seemed to be either because no one would voice an objection to a bad idea, or because no one was able (or willing) to suggest a better alternative.

The faculty agree with the students' contention that there was not enough time for some teams to complete the problem. But, it is felt that the additional time is needed in teaching teamwork techniques, forming the teams and practicing teamwork skills and group decision making.

Technical

In Table 2 Points Awarded, the points for computer interface and for competition were added to provide incentive to the project. Computer interfaces were *not* covered in the course, and competition was *not* an element of the overall course grading scheme. Removing those points gives a clearer view of the technical performance of the teams. Table 3 shows the distribution of project scores for the class.

		project scores
		number of teams
A	9.0 – 10	4
B	8.0 - 8.9	3
C	7.0 - 7.9	3
D	6.0 - 6.9	2
	Mean	8.37
	standard deviation	1.1

Table 3 Distribution of Project Scores

Although we all would like to see all of the students 100% successful, this distribution of performance seems consistent with other elements of the course, and these students' performance in other courses.

Three of the projects exceeded specifications in all categories. One project literally "crashed and burned" during the demonstration. Subjectively, the course instructors feel that all of the failures-to-meet-specification can be attributed to team work issues, and will be presented later in this section.

Continuing Teamwork Approaches

The course has been offered several times since this trial was run. The successive offerings of the course have continued to build on the teaming concepts. For example the following offering of this course was built on these results. The entire course was designed to be team centered. Students were divided into teams during the first week. A week's worth of training and exercises was dedicated to team forming, storming and norming. The course was organized into three blocks, one for each hardware block of the project. Class time was arranged into two, three hour blocks, with lecture and lab facilities available during the entire six hours. Each team decided (subject to faculty approval) what learning activities they wanted to follow each week. Two-thirds of the way through each block, the associated major course exam was administered to each student individually. The remainder of the time within that block was dedicated to the teams' design, fabrication, testing, modification, and documentation of the hardware and software necessary to implement that block. Each student's grade was strong mix of individual performance on weekly quizzes and the major exams, and the team's performance on project management, and project performance, as well as the team's average performance on the quizzes and exams.

Most recently the course breaks the students into teams of four or five which work together as a team in both lecture and laboratory. The course, however has taken on a somewhat more structured approach than the previous description. The teams work together on homework, laboratory assignments, and function as a group during lecture activities. Exams, quizzes and laboratory reports continue to be an individual effort. However, a bounus of 5% is offered on exams for teams whose members all score above 80%. The current offering will also incorporate the all-day design project described in this paper.

Biographical Information

J. Michael Jacob is a Distinguished Professor of Technology, and a professor in the Department of Electrical Engineering Technology at Purdue University, W. Lafayette, IN. Professor Jacob is nationally recognized as a leader in undergraduate education. He has authored and presented numerous textbooks, papers, workshops, etc. at the national level.

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