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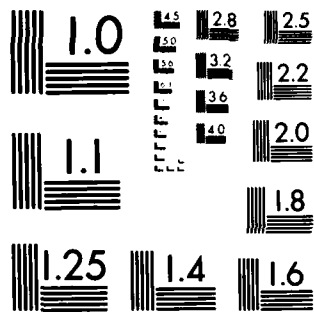
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# OPERATION STALACTITE: LIGHT EDUCATION

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## Abstract

Operation Stalactite was a senior project to design and build a frequency stabilized Helium-Neon laser. We shall review the project objectives, approach, and teaching techniques. Insights into student interactions and efforts to focus an undergraduate education will be given. Stalactite required the students to organize, plan, propose, and execute a research plan in accordance with a schedule and budget. Reactions, educational benefits, and results of a post-project survey will be given.

## Introduction

We will describe an interesting and profitable experience in teaching an Electrical Engineering design course. Operation Stalactite was a single project within the Electrical Engineering (EE) 464 Senior Electronics Design course required of all electrical engineering and engineering science majors at the U.S. Air Force Academy. We will describe the objectives of the EE 464 course, the basic idea of Stalactite, the project objectives, approach, and the teaching techniques we used. We shall also discuss the concept of technical marketing and its importance in stimulating student interest. The results of the course were very encouraging as we viewed the impact they had on future engineering plans of our students.

Project Stalactite and our Teaching Philosophy: A major goal of EE 464 was to exercise the design ability of the senior students. EE 464 serves as a capstone course for both electrical engineering and also for a broad spectrum of science and engineering majors. This is an essential aspect of the training of our future Air Force officers. The course is designed to give the students an idea of how a Research and Development (R&D) contract is directed. Before the project started in January of 1981, an announcement was sent to all prospective EE 464 students. This announcement, similar to the Commerce Business Daily, listed possible projects. Cadets were required to submit a response indicating their interest and capability to do the research. One of these projects was Operation Stalactite. The requirements for EE 464, which covered 42 lessons, were: Lesson 5 - conceptual design review and draft of a proposed contract; the students drafted a contract which described how they would approach the problem and the anticipated resource requirements. Lesson 8 - final contract due. Lesson 14 - preliminary design review. Lesson 21 - critical design review. Lesson 42 - final report due. During finals week, a final oral report was given.

One of our major goals was to instill in the students the excitement and enjoyment we have for engineering research. The title of the project itself was chosen to catch their attention. This unusual title was conceived to describe the design and the construction of a extremely narrow frequency helium-neon laser, whose frequency was to be as stable as a rock; thus the project title, Operation Stalactite. Working with seniors, soon to be lieutenants, we chose to establish a more relaxed atmos-

phere than the usual classroom requires. For example, since most of the students were not familiar with the principle of how a laser works nor the mechanisms which we would use to stabilize the laser, we gave some introductory lectures on laser physics. Several of these lectures were given informally in a conference room with coffee cake and beverages available for the students. Extensive dialogue was encouraged in order to instill learning by discovery. Questions were asked to the students to stimulate their thinking. Another of our educational goals was to teach and demonstrate the rough order of magnitude calculations and techniques for experimental verification. For example, we asked the students what the frequency difference was between the longitudinal modes of the laser and how to measure the difference. It was encouraging to see them "grasp a megahertz" and how to measure it. The majority of the time was spent in the laboratory although some of the work was done individually by the students, who later came together to integrate the various project requirements.

Technical Approach of Operation Stalactite: The frequency stabilization technique was described by Baer, Kowalski, and Hall of the Joint Institute for Laboratory Astrophysics (JILA), Colorado University, Boulder, Colorado.<sup>1</sup> In the fall of 1980, we discussed with Dr. Hall the advisability of using such a state-of-the-art technique for a senior class. Dr. Hall felt that his technique would be quite appropriate and graciously agreed to review our approach with us at JILA.

We were interested in this laser frequency stabilization technique because of our project with a Passive Ring Resonant Gyroscope (PRRG). A PRRG must have a frequency stabilized laser. Therefore, our involvement in Operation Stalactite would especially meet the mission of the Frank J. Seiler Research Laboratory, doing basic research in a manner to stimulate involvement of the USAF Academy faculty and cadets. Operation Stalactite would give us first-hand insights into the frequency stabilization technique and perhaps give us ideas of how we might modify our design of a PRRG in order to take advantage of the particular stabilization technique to obtain better gyroscope performance.

Project Organization and Responsibilities: The six cadets assigned to this project were divided into two teams as shown in Figure 1.

## PROJECT LEADER

### LASER TEAM

Cadet 1 -  
Single Mode Operation  
Zeeman Split Line  
Cadet 2 -  
Attach PZT Laser Tube  
Cadet 3 -  
Pre-Amplifier for PZT  
Beat Signal

### ELECTRONICS TEAM

Cadet 4 -  
Phase Lock Loop  
Cadet 5 -  
Control and  
Digitization  
Cadet 6 -  
PZT and Heater  
Driver

Figure 1  
Operation Stalactite Organization

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The laser team had primary responsibility for modifying the laser and obtaining the beat frequency. Cadet Conley had the responsibility to obtain single mode operation and then Zeeman split the transition states and measure the beat frequency. Cadet Diehl designed the tube to hold the laser and attached the piezo-electric transducer to the tube. Cadet Anders designed and built the pre-amplifier for the beam signal. The electronics team had the responsibility of designing and constructing all the electronics required for the stabilization. A bandpass amplifier was designed by Cadet Calamoneri with a gain of 53 db at a center frequency of 300 KHz and a phase delay less than or equal to .08 of a second at 300 KHz. Cadet Poole had the responsibility of incorporating a phase locked loop (PLL) to increase the beat signal frequency from approximately 300 KHz to 30 MHz. Although this was not a portion of Dr. Hall's original design, he had suggested this as an improvement to his design. Cadet Lorenzini had the responsibility for the control and digitization. The counter based controller provided a 10 Hz square wave dither signal which was necessary to generate a digital error signal proportional to the offset from the desired stabilized frequency. The digital error signal was converted to an analog signal whose range was between  $\pm 10$  volts. This signal was provided to the piezo-electric transducer (PZT) driver, square rooter, and heater driver designed by Cadet Calamoneri. The square rooter was suggested by Dr. Hall to make the heater signal more proportional to the actual error signal.

The laser team had the responsibility of modifying the Spectra Physics 155 helium-neon laser and researching the other stabilization techniques that were cited in Baer, Kowalski, and Hall's paper. The first requirement, obtaining single longitudinal mode, was accomplished by bending the tube to misalign the two mirrors thus introducing a loss. This loss allowed only a single longitudinal mode to oscillate. In order to verify single mode operation, we constructed a Fabry-Perot interferometer. We aluminized 5 cm diameter flats, flat to approximately 50 nm. The flats were mounted in angular orientation devices and separated by about 10 cm. This was a good experience for the cadets to see application of instrumentation principles to make measurements they needed. The Fabry-Perot was also used to determine which direction the PZT moved when a plus voltage was applied to it. Another requirement was to obtain the beat frequency obtained from Zeeman-splitting the line by applying bar magnets. The laser team also designed and constructed the tube to hold the laser which is shown in Figure 2 along with the Stalactite team.

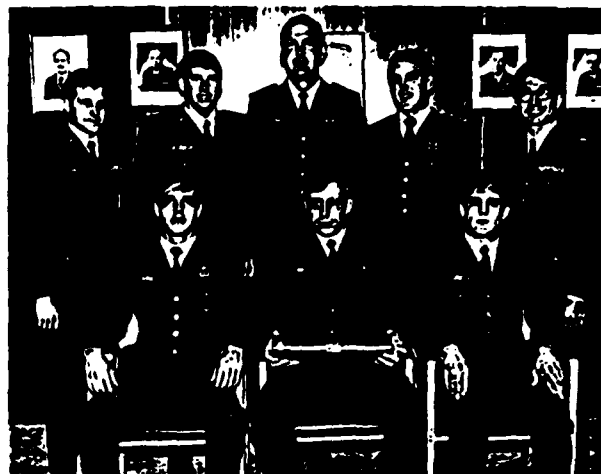


Figure 2  
Stalactite Team

Our class sessions were only 50 minutes in length making it difficult for the students to gain an appreciation for the requirement of steadfast perseverance to solve a problem. For example, after two class periods of unsuccessful attempts to measure the beat frequency of the Zeeman split lines, we stayed after class without the cadets for several hours until the proper alignment of the diode and settings on the oscilloscopes allowed us to measure the beat signal. The student leaders were called after we obtained this beat signal so they could share our excitement and enthusiasm for another successful step in the project.

The class visited Dr. Hall and Dr. Baer at their laboratory in Boulder, Colorado. This visit was valuable for several reasons. First, Dr. Hall and Dr. Baer were able to give us many specific insights and advice to make our job easier. Of equal importance was the enthusiasm they shared with us for their work and the demonstration of particular applications that they had of a frequency stabilized laser. It was an eyeopening experience for our students to see sophisticated studies being done with the frequency stabilized laser that Hall and Baer had developed.

**Results:** Our students gained significant understanding into requirements and methods of executing R&D. It was especially enlightening for them to estimate the cost for technician and machine-shop support for their work. We had them contact various shops (glass blower, machining) and the students then had to estimate the total cost. They were introduced to the concept of overhead costs which are hidden when estimating with just the material and salary costs. Their own labor was estimated as a fraction of their salary. The cost summary is given in the table, showing both their estimated and actual costs. It was important for them to see that the total project cost of about \$3000.00 was approximately equally divided between materials and labor.

#### COST STATUS REPORT

	ESTIMATE \$	ACTUAL \$
MATERIALS	1,440	1,555
PERSONNEL	1,020	1,520
TOTAL	2,460	3,075



The laser team successfully completed all of the requirements. Each cadet in the electronics team successfully completed the design, fabrication, and testing of their individual components. However, the semester ended before the subsystems could be successfully integrated. Lt Poole volunteered to return in the summer to continue working on the project. He integrated all the systems and obtained a frequency stabilization better than 10 MHz as measured on a Burleigh spherical Fabry-Perot. This spherical Fabry-Perot, with a separation of 50 centimeters had a bandwidth of 150 MHz. Our ability to measure the frequency stability was limited by the bandwidth of the spherical Fabry-Perot. We would like to improve the packaging of each system before we take the laser back to Dr. Hall, who has graciously offered to test our frequency stabilized laser against an iodine stabilized laser that he has.

At the end of the class, a questionnaire was given to each student. Their response was quite encouraging. The overwhelming reason why the students volunteered for this particular project was their interest in applying the electrical engineering principles to lasers. Our efforts to stimulate them with laser technology in the Commerce Daily Bulletin proved quite successful. Especially encouraging was one student's remarks that he had gotten more out of this course than any other he had had in his four years. The reason for this was he finally had the opportunity to use some of the engineering and physics he had learned, and the opportunity to do this with a free hand. Several students remarked how they enjoyed the opportunity to work independently and learn from their own mistakes. An additional benefit for the students was the interaction they had with the various technicians. This interaction gave them insight into the roles they would have as junior engineers and officers working with technicians. Another student remarked that he had changed his plans for graduate education from a masters degree in business to a masters degree in engineering because he enjoyed this work so much.

#### Conclusion

In conclusion, Operation Stalactite was a tremendous success. The project stimulated the students to focus four years of learning on a challenging project. The information we learned about control and frequency stabilization has been very valuable in our laser gyro research.

#### Acknowledgements

We are deeply indebted to Drs. Baer and Hall for their advice, participation, and especially the loan of crucial components permitting a timely fabrication schedule by the cadets. Major Joe Pollard advised on most of the electrical design and was a positive stimulus to the cadets to keep on schedule. MSgt Earl Barr provided the technician support and advice for the electrical fabrication. Mr. Carl Geddes built the container for the laser and Mr. Fred Kibler blew the glass to attach the PZT on the rear mirror of the laser.

#### Reference

1. T. Baer, F.V. Kowalski, and J.L. Hall, "Frequency Stabilization of a 0.633 micrometer He-Ne Longitudinal Zeeman Laser," Appl. Opt. 19: 3173 (1980).



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