FINAL REPORT

SURVEY OF LASER RANGE LIGHT DEVELOPMENTS AND FINAL RESULTS ON TWO-COLOUR LASER RANGE LIGHT AT POINTE-À-BASILE

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Executive Summary

The laser range light project has been initiated by the Canadian Coast Guard to reduce the costs associated with maintenance of range lights. Possibilities were advanced for decreasing the costs associated with the current need for two sites to provide a range light for mariners using one single tower. Reducing the power consumption was also aimed in order to decrease the costs associated with solar power supplies.

A first prototype was installed in December of 1995 at St-Michel-de-Bellechasse (30 km range). Tests demonstrated that the system performed well regarding this technology but had to be improved in order to guide the mariners in the channel. Brightness of the laser has been estimated to be four times that of the standard range lights.

A second prototype was installed in June of 2000 on the Hay River channel with a two colour light code that lets the mariners know if they are on the starboard side, port side or centre of the channel. This short range system has proven to be easy to install and to maintain by CCG personnel and the light codes have proven to be very easily identifiable.

A third prototype was installed at Pointe-à-Basile in July of 2001. This prototype includes a new scanning mechanism producing 11 light codes at 11 different angles taking into account the channel's length (15 km) and the need for a better guiding signal on the edges of the channel. Observation showed that conspicuousness of the system was more than enough since a power reduction of 85% has been needed to make lasers as comfortable as the standard range lights. Observation also showed that the three central codes were easy to distinguish from each other but other codes were almost indistinguishable.

After a one-year test at Pointe-à-Basile, reliability of the main system components has been demonstrated. The only failures that were observed when the system was inspected at the end of the tests were two set screws that were completely unscrewed in the scanning mechanism. This led to a slack in the rotating mechanism and since the laser electronic switching control was synchronized on this mechanism, the lasers automatically switched off every time shaft position was out of range and in the worst cases, the system had to be reset. Although it would be easy to prevent such a failure by a simple modification of one mechanical part, we will see in this report that a system without any moving component would present more advantages. Based on the evaluation of the system, components are most likely to wear the lifetime of the system which is estimated at ten years.

When we consider what have been learned with the three prototypes and what characteristics must be modified to fit the users needs we can conclude that the information and expertise acquired so far are sufficient to make the next system the final version. Three possible system configurations are presented at the end of this report.

The simplest one would be a single red laser without any scanning mechanism that would be shined toward the centre of the channel. This system could be either turned on on demand when bad weather makes standard range lights inefficient or it could be used as main lights, and boosted on demand to increase the light output in bad weather conditions. A second configuration would be a red and a green laser without any scanning mechanism that would give three light codes similar to the ones used at Hay River and the third system configuration would use 4 lasers to provide 7 easily distinguishable light codes. However before any final system design is made the participation of mariners and Canadian Coast Guard is required to make sure all requirements are taken into account when the final prototype is fabricated.

1 Introduction

This report describes mainly the prototype Two-Colour Laser Range Light developed by INO and installed at Pointe-à-Basile for a one-year test. However a survey of the complete laser range light development program will also be presented in order to place the current work into context.

The Pointe-à-Basile prototype was designed for ranges as long as 30 km and it has 11 lateral laser codes to give better alignment accuracy for long navigation channels. Three sites were considered during the project to test the prototype: St-Michel, Cap-Santé and Pointe-à-Basile. The system characteristics reflect the requirements of these three sites although only Pointe-à-Basile has been finally chosen for the tests.

A description of the specific project goals and a description of the final system will be presented and the results of the one-year test made at Pointe-à-Basile will be discussed including an evaluation of the system worn state.

Finally, the last sections are a summary of what have been learned throughout this program and solutions to encountered problems will be suggested. Conclusion will present what the next development steps should be to end up with a commercially available version of the laser range light.

2 Previous Work

2.1 Project Background

The laser range light project has been initiated by the Canadian Coast Guard to reduce the costs associated with range lights maintenance. Possibilities were advanced to decrease the costs associated with the current need for two sites to provide a range light for mariners using one single tower. Reducing the power consumption was also aimed in order to decrease the costs associated with solar power supplies. The option of using a more powerful, more efficient and more accurate light source capable of providing adequate and fast information to mariners was then adopted. This decision was based on the possible saving for the CCG. The goal was to have a light on one single tower, and provide the level of servicing required to the mariners. The new source had to be at least as conspicuous as standard range lights and an approach that would overcome the problem of background light pollution would be a bonus.

The light source selected for the new range light was the laser. As we will see throughout this report, the laser has the potential of fulfilling all of those requirements. The three tested prototypes have already met most of the expected requirements. The improvements that need to be implemented in the next and final prototype will be discussed in sections 7 and 8.

Figure 2.1 shows how the laser light could allow the use of only one tower instead of two. With the standard approach, mariners can see two vertically aligned lights when they are in the centre of the channel. With the laser range, a specific lighting code is directed to the mariners depending where they are in the channel. For example, a mariner in the centre of the maritime channel could see the range light flashing alternatively red and green and on the starboard or port side of the channel he could see a one colour (red or green) flashing light.

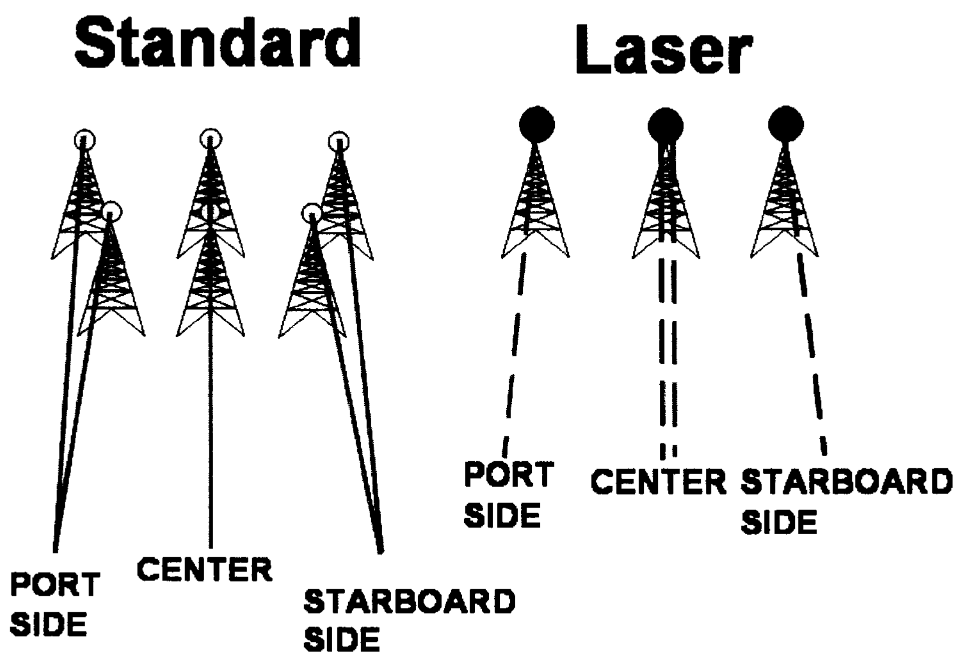


Figure 2.1 Standard Ranges compared to Laser Ranges *(simple dashed lines represent one colour flashing lights and double dashed line represents alternative two-colour flashing light).*

2.2 First Prototype (long range, one-colour, installed at St-Michel)

The development of the green laser range light began in April of 1995. The goal was to determine the potential of laser sources as aids to navigation. This was to be achieved by direct comparison of laser and conventional lights visibility in different weather conditions. To evaluate the potential of laser technology for long ranges, St-Michel de

Bellechasse site has been chosen for the test. This channel is approximately 21 km long by 300 m wide and since the laser had to be installed on the rear tower of the range at 8 km from the first buoys, the laser had to be conspicuous at a distance as far as 30 km. The system was first installed in the tower in December of 1995 (Figure 2.2).

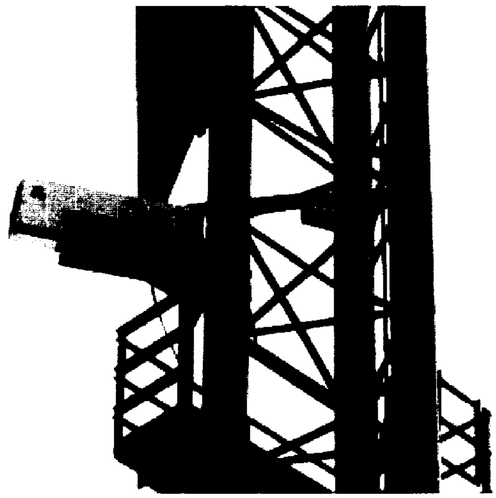


Figure 2.2 Prototype installed at St-Michel de Bellechasse.

Figure 2.3 and Figure 2.4 show an inside view of the system where we can see the laser, mirrors and electronics. The system dimensions were approximately: 18" x 50" x 13" with the protective roof or 16" x 38" x 7" without it. Its weight was roughly 100 pounds. The system electrical power consumption was estimated to be approximately 30W. An electrical protection circuit ensures the system resistance against thunder storms and lightning.

To provide the mariners with an alignment signal when they are not in the centre of the channel, a scanning mechanism (rotating mirror) has been implemented in the prototype to make the laser beam sweep across the channel. A code was produced by the scanning of the mirror in the system (2) which induced a sweep of the laser beam (4) in the channel. This way the pilots should see different lighting signals in relation with their position in the channel (Figure 2.5).

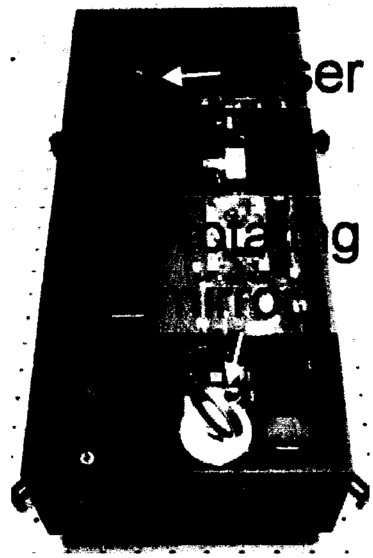
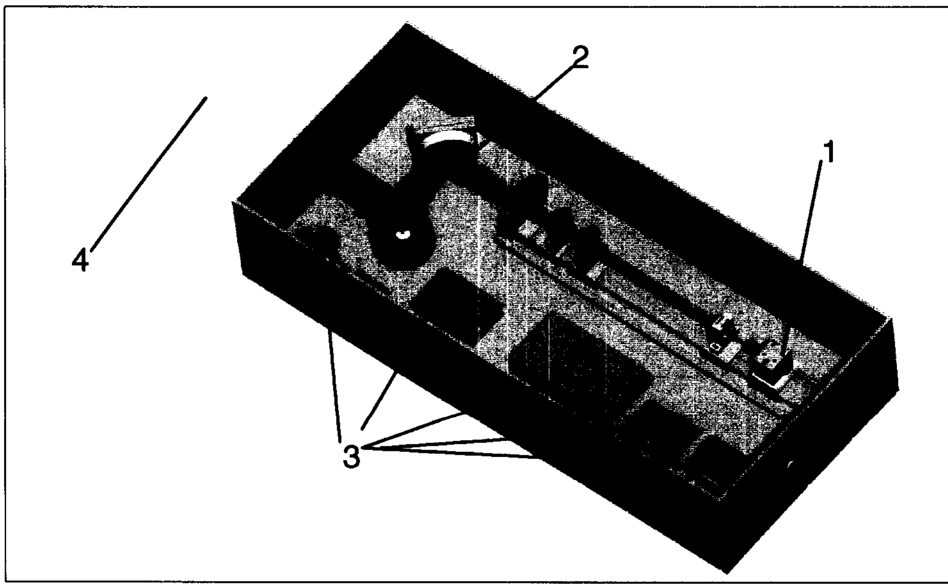


Figure 2.3 : Picture of St-Michel-de-Bellechasse prototype.



Legend	
1	Laser
2	Scanning mirror
3	Electronic modules
4	Scanning laser beam

Figure 2.4 : Schematic of St-Michel-de-Bellechasse prototype.

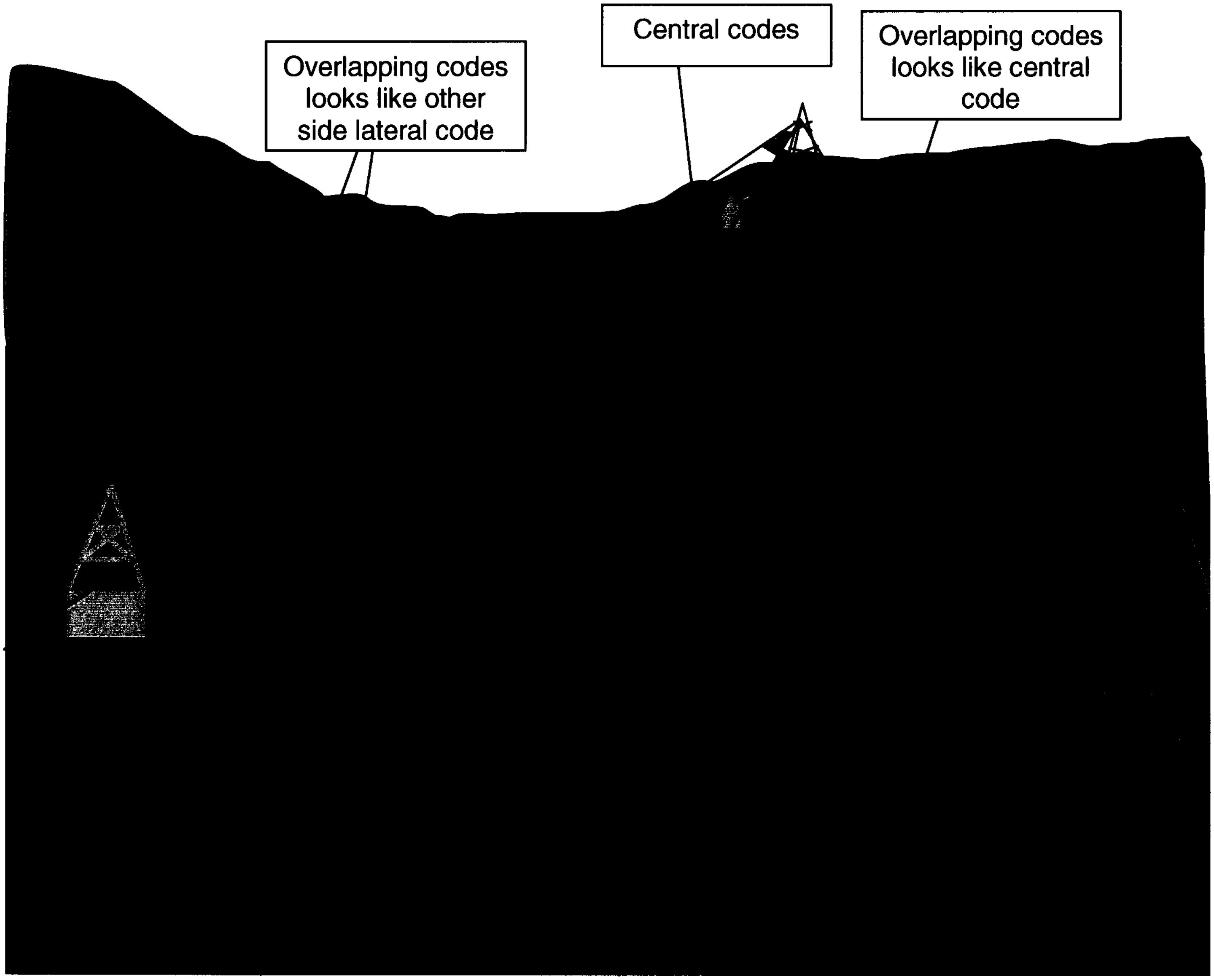


Figure 2.5 : Codes representation (travelling light waves) on the river within buoys and possible misinterpretation of codes.

Here is a summary of what have been learned with this prototype:

- A scanning mechanism that can modify the laser beam alignment if wearing occurs should not be used anymore in any future system since it may give pilot bad alignment information.
- The system was inefficient in providing the pilot a clear information on whether they were on the starboard or port side of the channel (Figure 2.5) and a two-colour system will be needed in the future if operation with a single tower is still desired. (However, the system has proven to be efficient in the centre of the channel).

- A gun scope must be added to the next systems to ease the alignment of the system.
- The electrical protection that was installed in the system has proven to be efficient and must be included in any future laser range light.
- Regarding the conspicuousness of the system, the observation proved that it was more than satisfactory since it has been estimated to be four times that of the standard range light.
- Even with climatic conditions like fog, rain, snow or great distances, mariners reported that the light always stayed the same colour, which is a clear advantage for distinguishing the light from other surrounding lights.

2.3 Second Prototype (short range, two-colours, installed at Hay River)

The tests made at St-Michel with the first prototype raised an important issue about the system's efficiency when mariners are on the edges of the navigation channel. A better light code had to be developed in order to let mariners know if they are on the starboard side, port side or centre of the channel. The laser range light developed for the Hay River solved that problem with a Two-Colours approach which is illustrated in Figure 2.6 and Figure 2.7.

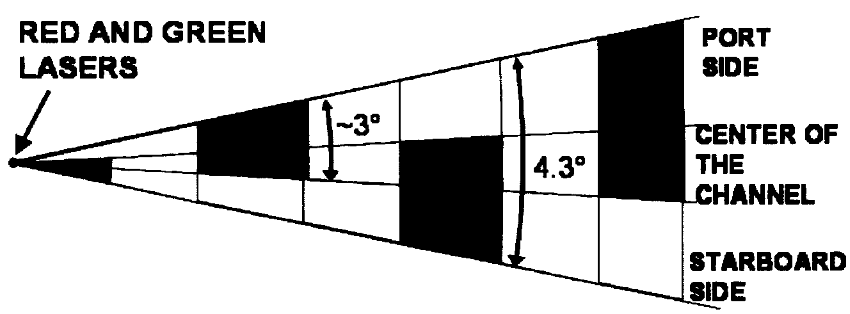


Figure 2.6 Two-Colours light code of the Hay River prototype.

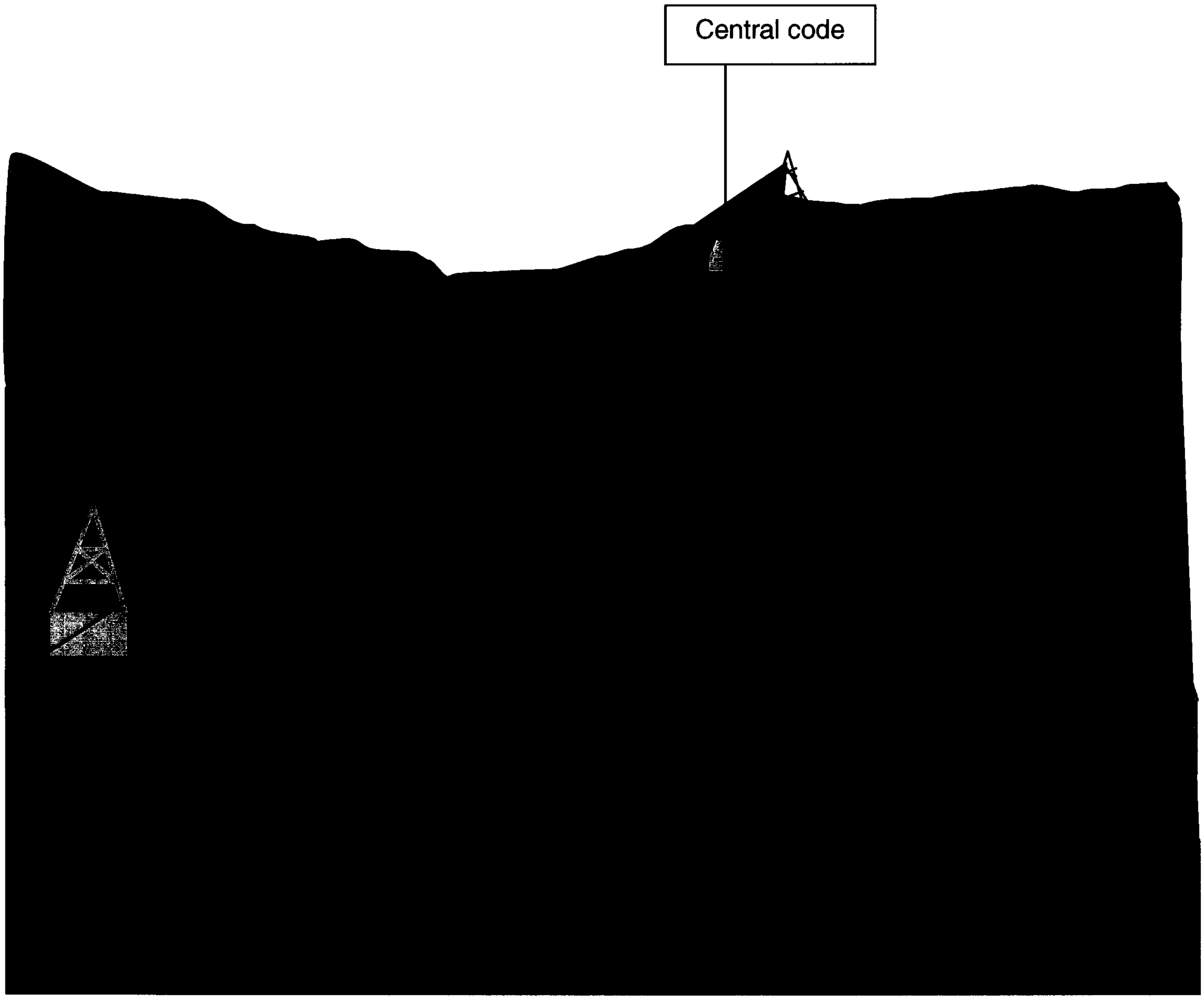
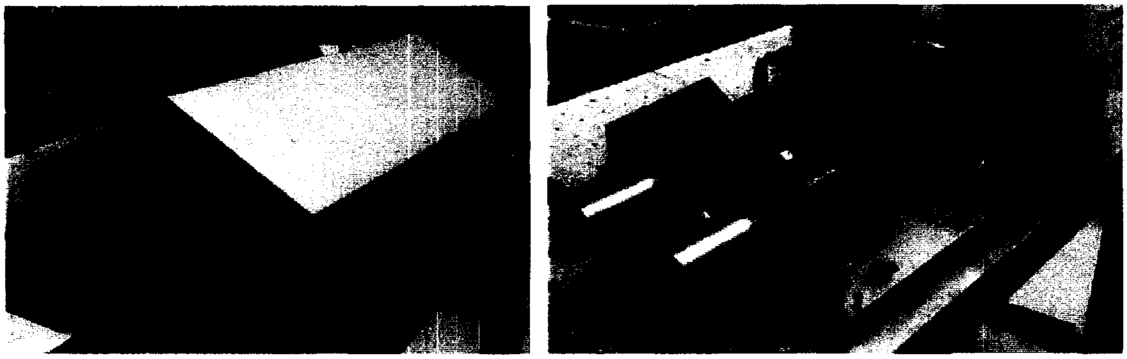


Figure 2.7 Illustration showing the code representation (travelling light waves) on the river within buoys.

The system consists of two flashing laser beams (Figure 2.9) that have each approximately 3 degrees of horizontal divergence. These beams partly overlap in the centre of the channel (Figure 2.7) to give the mariners alternate green and red signals. On the edge of the channel, signals have only one colour.

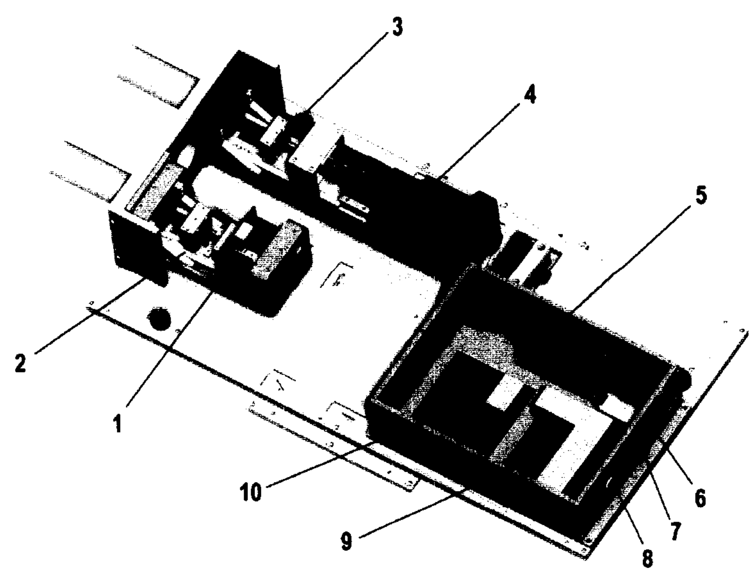
This prototype has been designed with a modular approach (Figure 2.8 and Figure 2.9). Its dimensions were: 17" x 37" x 11" with its protective roof and 17" x 35" x 7" without it. Its overall weight was approximately 100 pounds. In Figure 2.9, we can see that the system is made of 3 modules (red laser (2), green laser (3) and electronics (9)).

Electronics include a Day/Night Detector (8) to adjust the power level of the system at night and a Transient Voltage Protector Board (10) to eliminate lightning spikes and voltage variations. A gun scope (5) has been incorporated in the system (central aperture on the photo) to ease the alignment on site.



a) b)

Figure 2.8 : a) Photos of Hay River prototype completely assembled, b) Hay River prototype with cover removed.



Legend

1	Red Laser Driver
2	Red Laser Channel Assembly
3	Green Laser Channel Assembly
4	Green Laser Driver
5	Alignment Telescope
6	Spark Counter
7	Power Input Connector
8	Day / Night Detector
9	Control Electronics
10	Transient Voltage Protector Board

Figure 2.9 : Hay River prototype view of internal components.

The system was installed in Hay River in June of 2000. It was powered by solar equipment and has an electrical consumption of approximately 30 W. It has proven to be easy to install and maintain by CCG personnel. The light code has proven to be very easily identifiable. In summary, this system has performed as expected.

Here is a summary of what have been learned with this prototype:

- A power adjustment device should be included in the system to allow on-site adjustment of each laser power separately.
- The two-colours approach have proven to be as efficient on the sides of the channel than it is in the centre.
- The gun scope included in the system greatly simplified the alignment procedure of the laser range light.
- The low consumption of the system was appropriate for solar power.

3 Specifics Goals for Pointe-à-Basile and Chosen Approach

The main goals behind the development of the Pointe-à-Basile prototype can be summarised as follows:

A. To have a code as easy to identify as the Hay River one.
B. To have a conspicuousness at long distance as good as the St-Michel prototype.
C. To have more light codes than the Hay River prototype to match long maritime channels and give more precise position information when mariners are on the sides of the channels.

Basically the approach used to fulfil those requirements has been to use two laser colours as in Hay River prototype and to use high laser intensity as in St-Michel-de-Bellechasse prototype. Goal C. can be considered as the requirement that asked for most of the effort spent on the project. A major task of the project has consisted in developing a multi-laser beam system that shines simultaneously at different positions of the maritime channel with different colours and flashing codes. Figure 3.1 shows the lighting approach that has been selected to give mariners position information throughout the maritime channel.

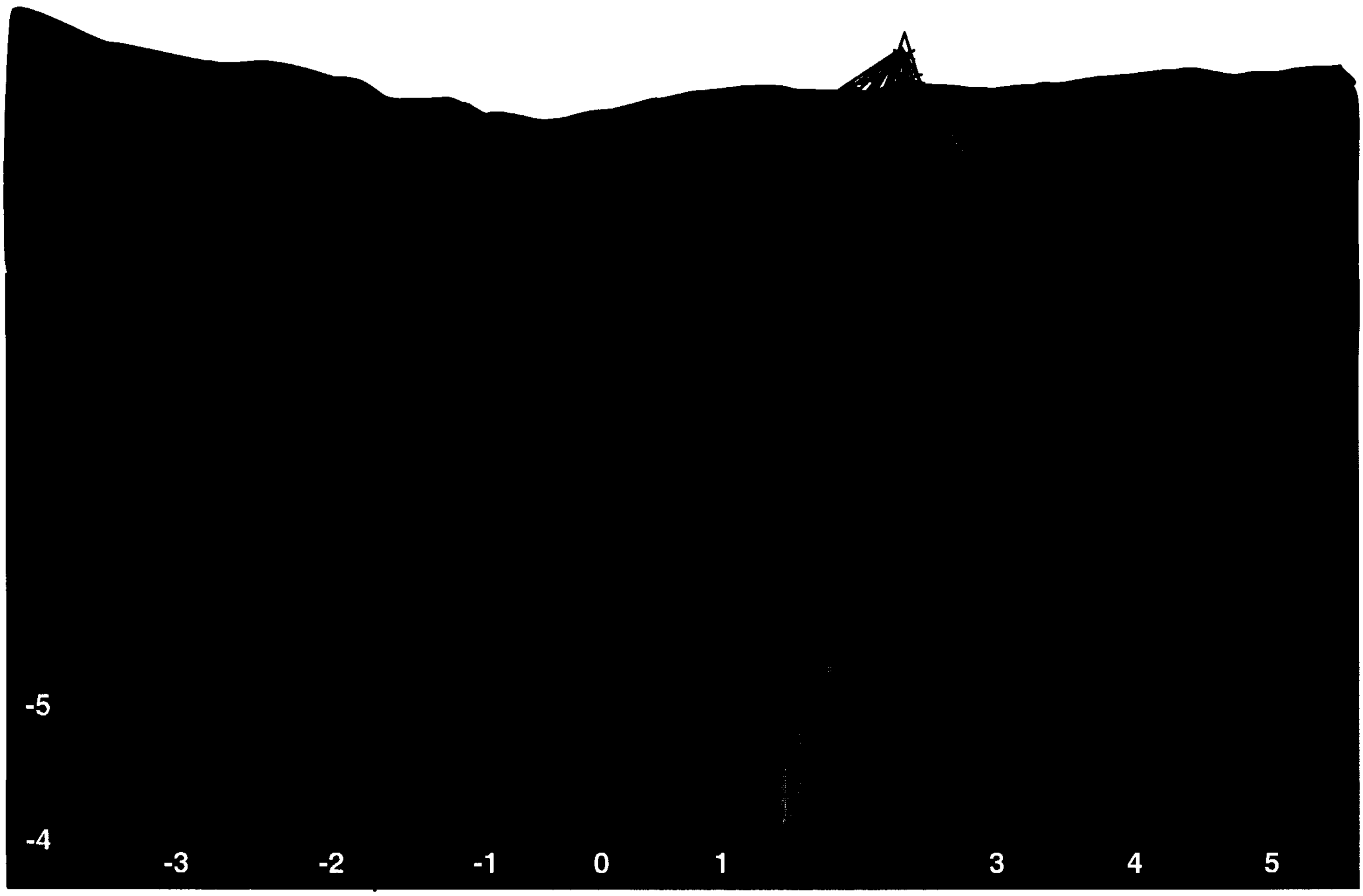


Figure 3.1 : Illustration showing the code representation (travelling light waves) on the river within buoys for Pointe-à-Basile prototype.

As with the Hay River prototype, an alternatively red and green flashing code shines the centre of the channel (code 0) and a slow one-colour flashing code shines on each side of that area (codes ±1). Codes ±2, 3, 4 and 5 have been added to cover the area closer to the first buoys. Those additional codes distinguish themselves from the central codes by higher flashing frequencies. The higher the frequency, the closer the vessel is from the edge of the channel. However, as it has been learned once the system was installed, the lateral codes could superimposed over one another at transition and this led to misinterpretation of codes by mariners.

The project has additional objectives that had a strong influence on the prototype's design:

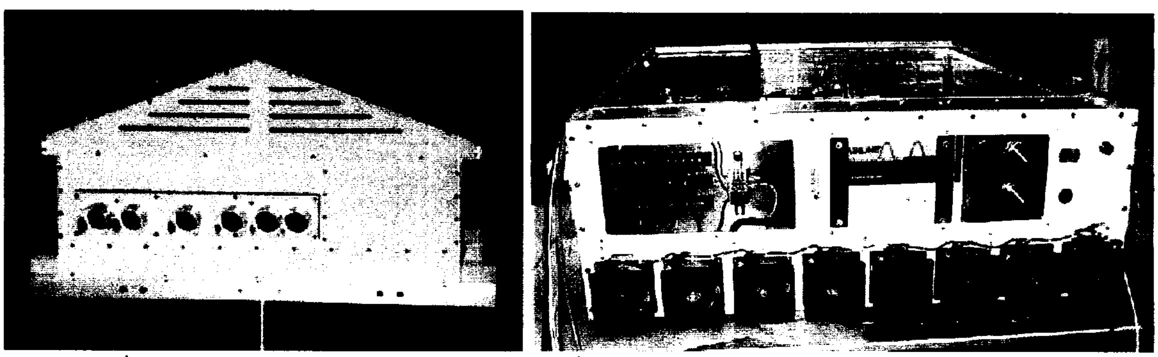
a) To include a system that would modify the laser power to compensate for bad visibility conditions.
b) To test several types of lasers at the same time to select the ones that best suit the application.
c) To lower production costs (the system couldn't use as many lasers as the number of light codes).

d) To develop a laser scanning mechanism without any lateral shift with wearing.
e) To be able to remotely monitor and modify the system parameters with a modem communication unit
f) To have enough flexibility to be installed also at Cap-Santé and at St-Michel-de-Bellechasse.

All those requirements led to a rather complex design and a big and heavy system.

4 Description of the System

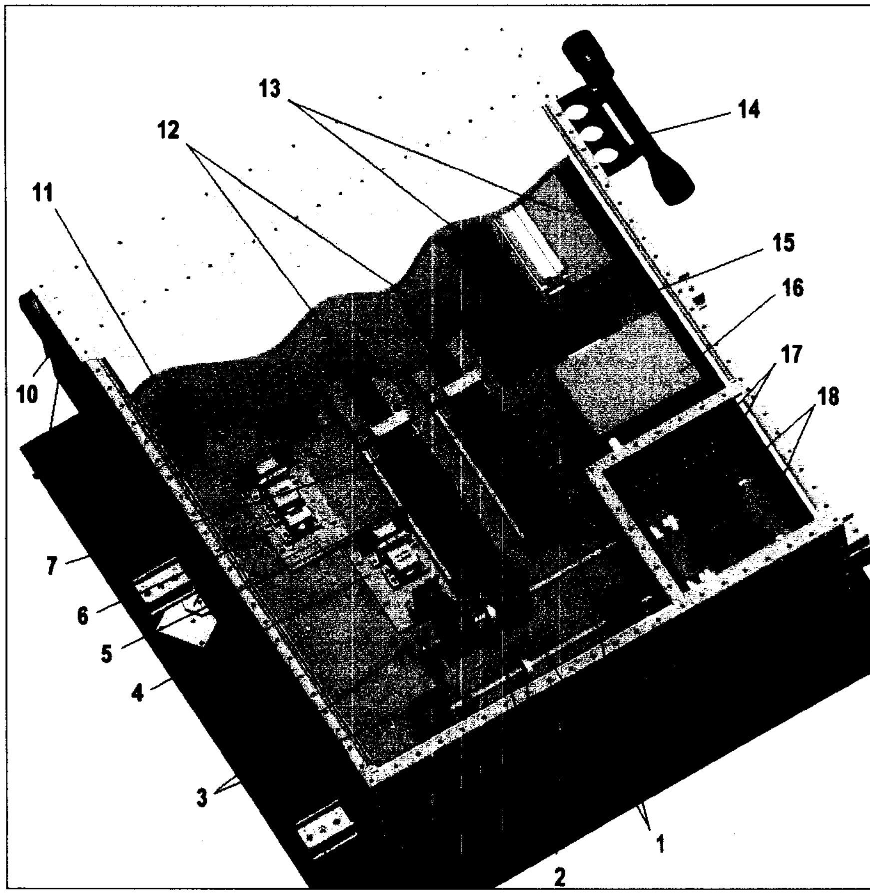
Figure 4.1 shows photos of the complete system as it was prior to its installation at Pointe-à-Basile. The approach used to package this system was to build a large thermally insulated and hermetically sealed box. The box had to be large enough to place all of the system modules on a single plate with enough free space to make modifications easy during the project. The system dimensions were approximately: 33" x 46" x 24" with the protective roof and 31" x 46" x 11" without it. Its weight was greater than 220 pounds. As can be seen on photo a) the system is equipped with six output windows. Two of those windows were required to adapt the system for Cap-Santé but only four of them were used in the project since the system was finally tested at Pointe-à-Basile.



a) b)

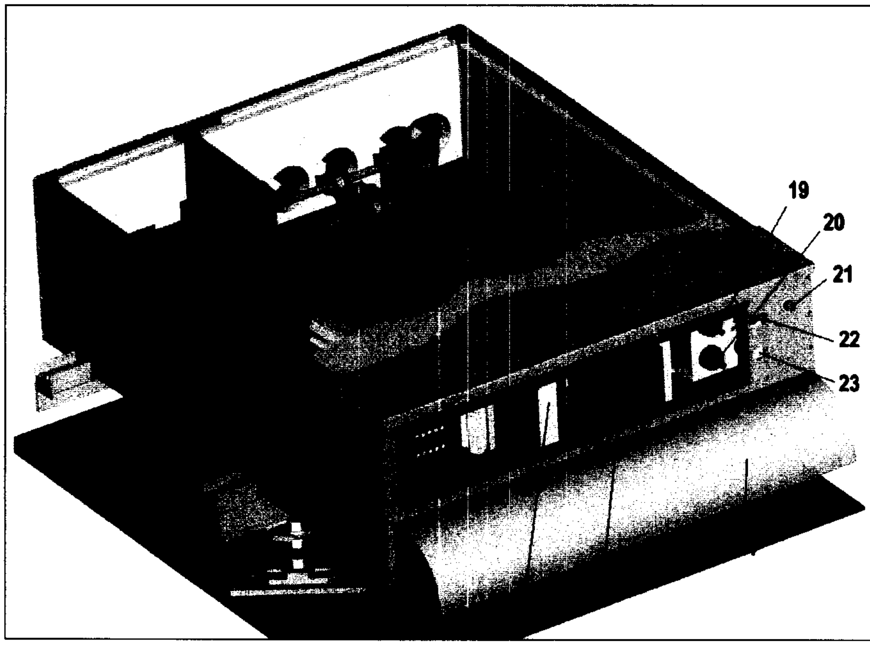
Figure 4.1 : Pointe-à-Basile Two-Colour Range Light Prototype, a) front view of fully assembled prototype, b) rear view without cover and roof.

Figure 4.2 shows an inside view of the system. Most important parts of the system are identified on that drawing. Heating elements (1) were used to ensure temperature level of windows and lasers. Red and green lasers in the centre of the system (4 and 5) have been used to generate codes in the centre of the channel while two other lasers (6 and 7) were used to generate codes on channel edges. Optical encoders (2) were used to synchronize codes with one another. A fog detector (not shown) can be connected to the system (10). The telescope (14) used to align the system can be seen and has proven to be useful in the system installation. Other components are also visible such as motors (18) and Geneva mechanisms (17) which drive shafts used to generate codes within the channel. Thermostat (8) and farmostat (15) have also been used to control the system temperature. Electronic circuits (12) controlling the system are placed over lasers and power supplies.



Legend	
1	Heating Elements
2	Motor Optical Encoders
3	Wedge Mounts
4	Red Laser Middle Channel Assembly
5	Green Laser Middle Channel Assembly
6	Red Laser Edge Channel Assembly
7	Green Laser Edge Channel Assembly
8	Thermostat
9	Power Input Connector
10	Retro-Diffusion Connector
11	Red Laser Drivers
12	Control Electronics
13	Power Supplies
14	Alignment Telescope
15	Farmostat
16	Green Laser Drivers
17	Geneva Mechanism
18	Motors

Figure 4.2 : Illustration of inside main components of Pointe-à-Basile prototype.



Legend	
19	Heating Switch
20	On / Off Switch
21	Day / Night Detector
22	Spike Counter
23	Power On Light
24	Fan Channel
25	Spike Count Board
26	Transient Voltage Suppressor

Figure 4.3 : Illustration of rear view of Pointe-à-Basile prototype.

Figure 4.3 also shows the system but from the rear. Power on light (23), spike counter (22) and Day/Night detector (21) can be seen. A small panel easily removed allows access to heating (19) and On/Off (20) switches and also to transient voltage suppresser (26) and spike count circuits (25). The fan channel (24) is also visible.

One of the major characteristics that makes the Pointe-à-Basile system different from the two previous prototypes is the scanning mechanism that was used to produce 11 light codes at 11 different angles with only 4 laser modules (Figure 4.4). Wedges are kind of prisms allowing to deviate light beams when placed on their paths. The mechanism consists of 4 pairs of wedges mounted on two rotating shafts. In operation, the laser beams pass trough the wedges below the shafts and are deviated according to each wedges characteristics. When the shaft rotates, different wedges are placed in the beam path and they deviate the beam at different angles producing different part of the codes. Codes from Figure 4.4 can be correlated with the ones from Figure 3.1.

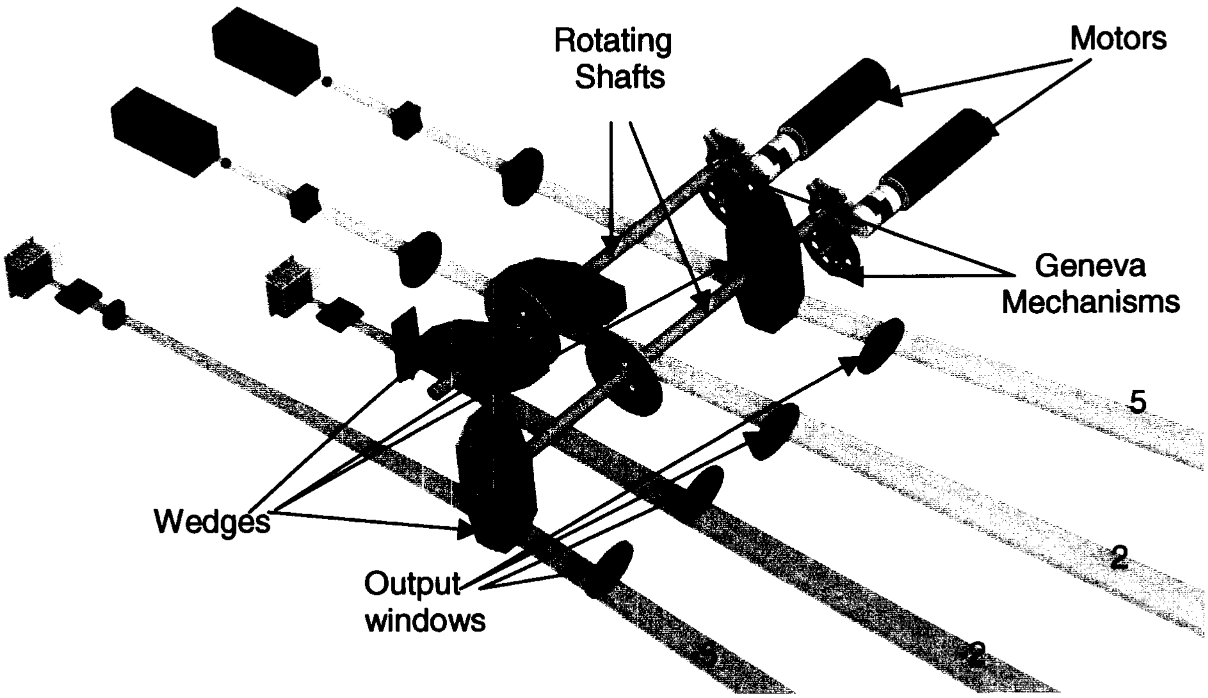
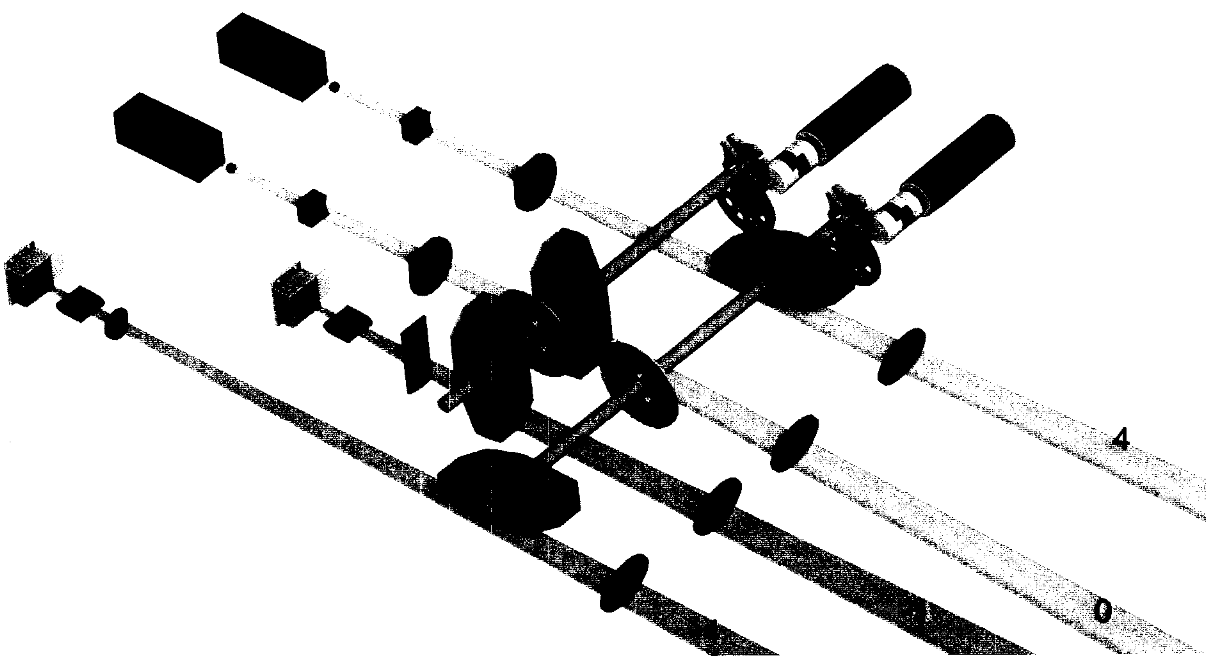
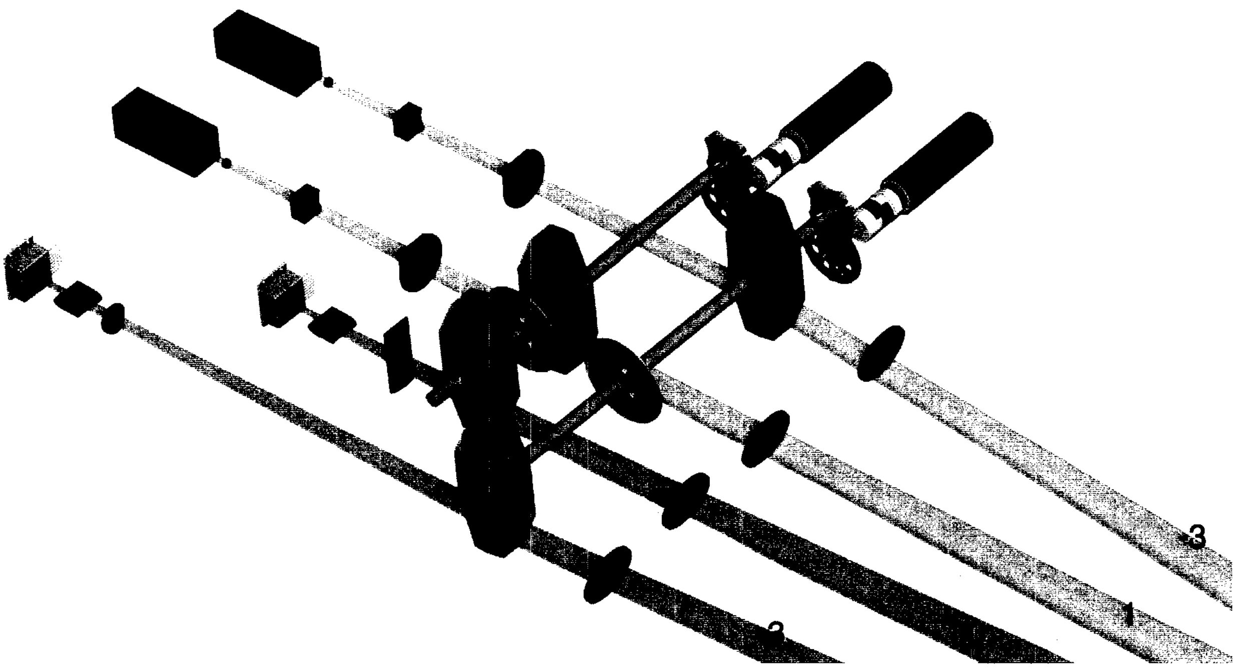


Figure 4.4 : Illustration of the mechanism allowing the production of codes with 4 wedge pairs mounted on shafts and 4 lasers (2 green and 2 red lasers). A) codes ±2 and ±5;



B) codes 0(green), -1, ±4



C) codes 0(red), 1, ±3

The diameter of wedges is 2 inches. Normally, a diameter of 1 inch would have been sufficient for each laser beam but at the beginning of the project, there was no red laser diode available with enough power and 4 lasers per red modules were planned. Later in the project, the laser diodes were replaced with more powerful ones, but it was too late to redesign the scanning mechanism to take this improvement into account.

Prior to system installation, maximum power of all laser beams were measured at the output of the system and results are presented in Table 1. According to theoretical calculations, those power should have been 4 times too strong for Pointe-à-Basile since the system was designed to allow possible operation at St-Michel de Bellechasse without any modification. This factor 4 comes from the factor two in ranges that distinguishes both sites (15 km vs 30 km) and the square law that applies when divergence of the system is kept constant.

Table 1 : Maximum output laser power of the Pointe-à-Basile Two-Colour Laser Range Light

System output maximum laser power	Central beams	Lateral beams
Red laser	0.1661 W	0.0653 W
Green laser	0.0956 W	0.0719 W

Divergence of each beam was adjusted to 0.25° (FWHM) horizontally and to 0.5°vertically. These angles were specifically adjusted for Pointe-à-Basile. They would almost perfectly fit Cap-Santé site but would be far too large for St-Michel. Test at St-Michel would only show that the system is conspicuous enough at 30 km even with higher divergences than those required for this site.

5 Results of the one-year tests at Pointe-à-Basile

5.1 Choice of Site for Tests

Pointe-à-Basile was finally selected for the system's final tests. It has been found that an installation at Cap-Santé would be too confusing for the mariners since the vertical separation between the laser range and the standard ranges would be too small to allow simultaneous use of both alignments. At Pointe-à-Basile the standard ranges and the laser range can easily be distinguished even at long distances, as can be seen in Figure 5.1. It was also decided not to test the system at St-Michel de Bellechasse since this site was considered only to test the conspicuousness of the system at 30 km and results obtained at Pointe-à-Basile clearly showed that lasers are even more visible than required.

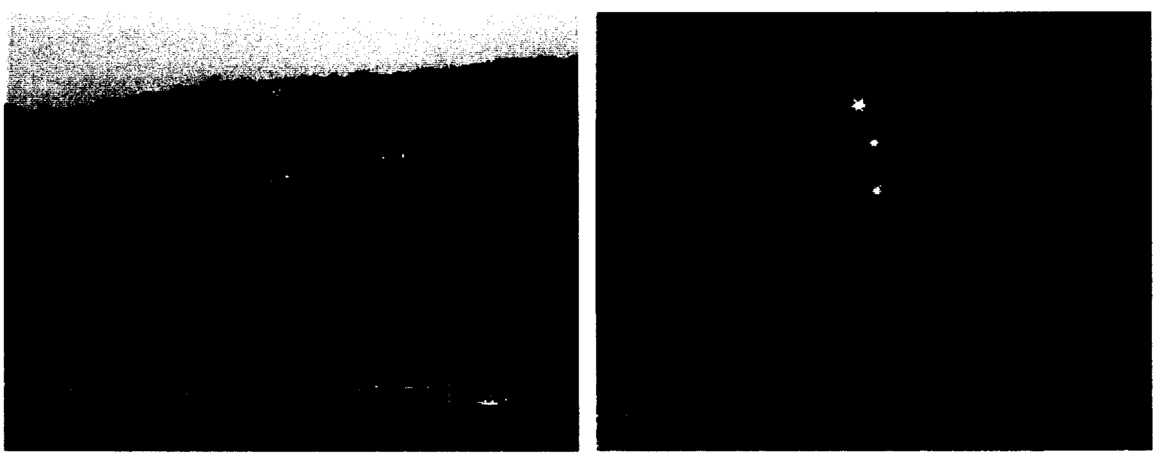


Figure 5.1 : a) Side view of the front tower of Pointe-à-Basile where was installed the two-colour-laser-range-light, b) Simultaneous view of standard set of ranges and laser-range from the maritime channel.

5.2 Installation

The system was installed at Pointe-à-Basile on July 12th, 2001 (Figure 5.2). Once the system was in the tower, installation of the system was an easy process. All mechanical support and electronic supplies were ready for quick installation. As at Hay River, the gun scope installed on the edge of the system proved to be very efficient to help aligning the system.

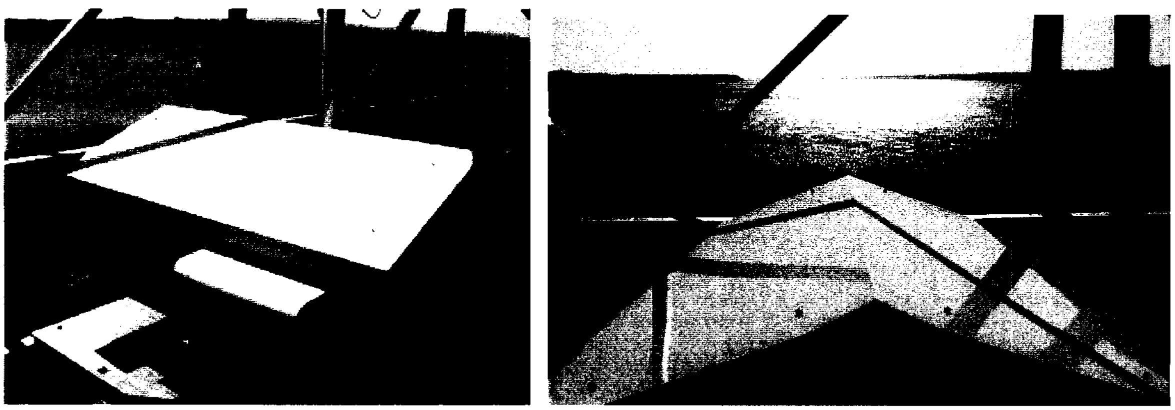


Figure 5.2 : Two-colour-laser-range-light in the front tower of Pointe-à-Basile.

5.3 Observations and Modifications

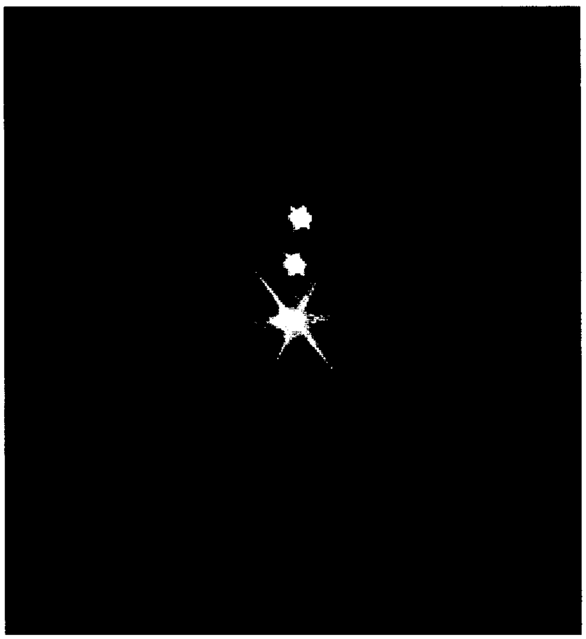
First, observation made by the mariners showed that the intensity of the light beams was too strong. On September 12th, a first reduction of the laser power was made (15% reduction for the red laser and 50% for the green).

On September 19th, 2001, observation of the light codes was made from a boat with Canadian Coast Guard staff. The light codes were observed before darkness and in night conditions. Atmospheric visibility was very good that night and, in those conditions, the strong conspicuousness of the system showed some disadvantages. Table 2 presents a summary of the observations made at that moment.

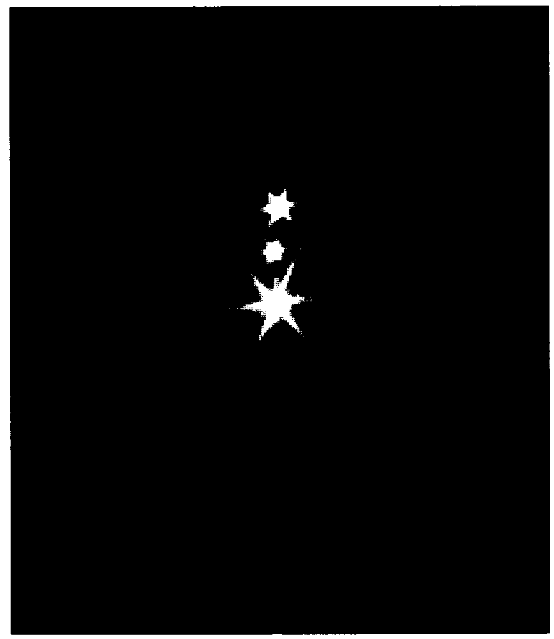
Table 2 : Summary of observations of the Pointe-à-Basile prototype after a first power adjustment was made on the system

Automatic power reduction worked properly and at the proper time (power of the system decreases by 90% in night conditions).
Both in day and night conditions the light intensity was still too strong even at the farthest observation location. Figure 5.3 a) and b).
Some stray light escaping from the system was visible when the system should have looked black. (In bad visibility conditions this

behaviour wouldn't be observed since stray light would be too weak to be observed.)
Some mix of the two colours was produced by stray light. Colours were not as pure as they should be.
Light intensity was not uniform and variations were observed when moving across the maritime channel.
Central flashing codes were too slow.
The three central codes were easy to distinguish from each other but other codes were almost indistinguishable.



a)



b)

Figure 5.3 : Simultaneous view of the laser range light and standard set of ranges by night. a) and b) represent alternate red and green signal in the centre of the channel.

On October 16th, 2001, the power level of all light beams has been readjusted with the help of Canadian Coast Guard staff who were observing the light code from the St-Laurence river while INO' staff reduced the power level and system's stray light.

After this final adjustment, all light beams were at approximately 15% of their maximum power value (85% reduction). The power level was then considered comfortable enough and the stray light almost completely suppressed. That means that initially the system light intensity was approximately 7 times too strong for that site.

This modification solved the problem of light intensity but further comments from the mariners showed that the lateral codes were still difficult to distinguish. This can be understood from Figure 3.1. For example, if codes 3 and 4 are superimposed the resulting code would not be recognisable as one of those two codes and could lead to misinterpretation of the location in the channel from the mariners. One of next sections will present a solution that will make the lateral codes easy to distinguish.

5.3.1 Power required in the channel:

From measurements made after the system has been removed at Pointe-à-Basile, it was established that the required intensity in the channel in order to get a visible, but not too strong signal at day time, is 0,1 to 0,3 nW/cm^2 for the red and green lasers. The intensity being given in power per surface unit this value takes into account the divergence and range of the laser range lights.

Since the system was installed, it has worked properly most of the time but three system resets were needed in the weeks following the last power adjustment. During winter, the system has worked full time. Although intermittent shut downs of some lasers were observed during the remaining part of the one-year test one can conclude that reliability of all components of the system but one has been demonstrated as it will be described below.

5.4 Evaluation of the system worn state:

The system has been shut down in May 2002 and has been uninstalled to be analysed at INO's installation in order to evaluate the worn state of its components.

5.4.1 Lasers:

Laser powers have been measured to evaluate their worn state. One should note that although the output light intensity of the system had been reduced at approximately 15% of its maximum value to make them more comfortable for the mariners the internal light intensity of the system remained 100% since the output reduction was obtained by the addition of absorbing filters in the system. Then the maximum output powers mentioned below correspond to the no filter case.

Table 3 : Maximum output laser power of the Pointe-à-Basile Two-Colour Laser Range Light after near one year service

System output maximum laser power after one year service	Central beams	Lateral beams
Red laser	0.1083 W	0.0481 W
Green laser	0.0273 W	0.0560 W

Powers from the red lasers have gone down from 166,1 to 108,3 mW for the central beams and from 65,3 to 48,1 mW for the lateral beams. This is a power reduction of approximately 35 and 25 % respectively. The red lasers were not of equal intrinsic maximum power. The power of the central beams laser being more than twice the one of the lateral beams laser.

For the green lasers, the power has gone down from 95,6 to 27,3 mW for the central beam and from 71,1 to 56,0 mW for the lateral beams. This is a power reduction of approximately 75% and 25% respectively. Before installation, the central beams laser had an intrinsic power which was approximately 25% more powerful than the lateral beams laser. However, after one year of service at maximum power operation the central laser beam shows a spatial degradation and an important power reduction. The lateral laser beam shows a more uniform spatial uniformity and less power reduction.

From these results, one can extrapolate the life expectancy of lasers used in the current system. If we assume that a laser can be considered useful as long as its power is over 50% of its initial value then Figure 5.4 shows that one can expect the laser life to extend from 0.75 years up to nearly 2.5 years when they are operated full time at their maximum power level. The Central green laser which gives the shorter life expectancy was noted to be less stable from the start when first mounted in the system. This result surely represents the worst case but in a production context such a laser could be rejected after a simple initial inspection.

If lasers were operated under the maximum power level or only intermittently then a direct increase of the effective life expectancy would be obtained. For example: a laser operating at full power with a modulation having a 10% duty cycle would have its lifetime increase by at least a factor 10.

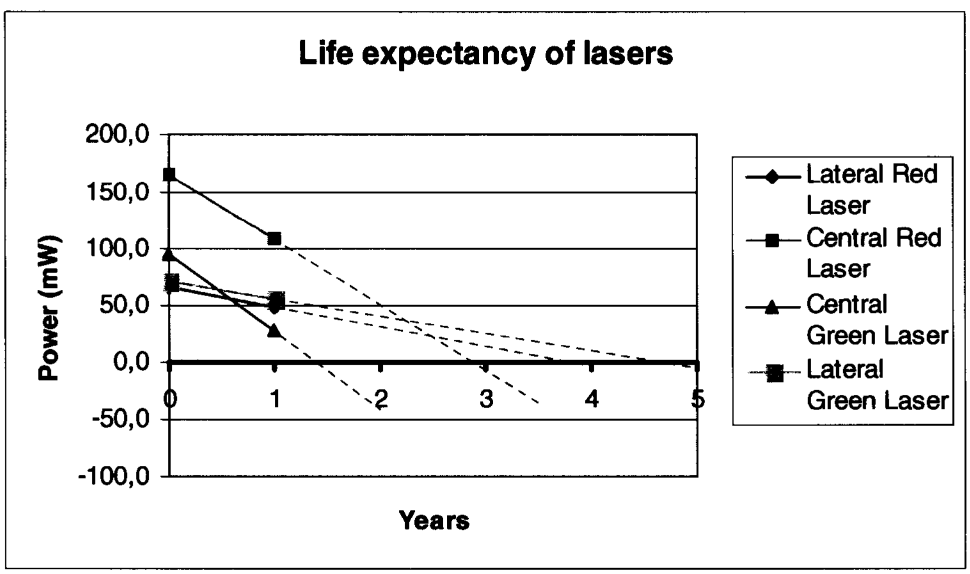


Figure 5.4 : Extrapolation of life expectancy of lasers from measured power after one year of operation.

Since tests made at Pointe-à-Basile showed that only 15% of the total laser power was required it would be possible to extend the life time of this system by a factor of 7 by a direct reduction of the laser power at the electronic level. During the test, reduction was made at the optics level and that's why it didn't change anything on the life time of the system. Then, we can conclude that once the power level of such a long range (15 to 30 km) system is properly electronically adjusted, its lifetime will be approximately 10 years.

5.4.2 Mechanical parts

The system has been put to work in laboratory conditions to evaluate its functionality. It has been found that the rotating mechanism had a backlash of 18 degrees. Such a backlash could be sufficient to completely prevent the system from working since the synchronization of the prototype was based on the rotating mechanism. During operation backlash could prevent the optical encoder to be properly aligned with the rotating shaft, leading to no signal produced to the transmission encoder at the right time. Eventually if this bad timing occurs too often, the software is unable to recover its proper timing and a faulty operation of the system occurs and lasers are shut down. This happened a few times during tests at Pointe-à-Basile and the same behavior have been observed in laboratory conditions as well.

It has been found that the problem came from a set screw in the Geneva Mechanism that was supposed to maintain the mechanism tightly bound to a notch. This set screw was no more at its place. The screw probably suffered enough vibrations, while the system was functioning, to unscrew by itself and to fall from its place. This locking technique must then be avoided in future system. Other locking techniques (such as splined shafts) should be used with fail proof properties with respect to wearing and misalignment.

All other parts of the rotating mechanism were in perfect condition and no apparent wearing could be observed even after a one-year test. No slack has been noted for any of the mounts in the system box, motors, ball bearings on shafts, and fans were still functioning perfectly. The internal parts of the system appear to be clean of any dust or water. No significant dust residues were present on optical windows which revealed that no significant amounts of rain or snow have reached them.

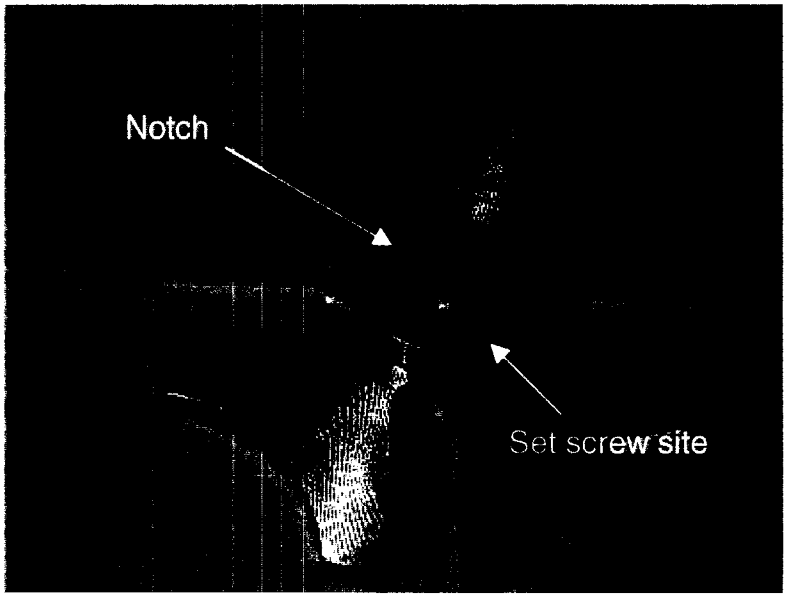


Figure 5.5 : The Geneva mechanism used to couple motors with rotating shafts.

5.4.3 Electronics and software

Electronics circuits have been evaluated with respect to their wearing and no significant wearing or damage have been noted. The Day/night detector, power supplies and laser drivers, spike counter are still working properly. The spike counter was at 19 counts including 3 resets of the system by CCG staff for faulty operations and few maintenance resets by INO's staff. The transient voltage suppresser circuit has worked well since no damage such as roasted or dark circuits or connectors have been observed. In the fuse panel, no fuse has been damaged.

The heating and cooling system are still functioning properly. Heating elements on optical windows were still in good conditions. The RS-232 communication link is still working properly. The electrical consumption has practically remained the same at approximately 550 W (with all heating elements and fans running) which is another indication of the good electronic condition of the system.

Regarding the software, the only noted problem comes from the synchronization of the Geneva mechanism which was faulty. The software was then not able to find the synchronization signal and shut down the red laser to avoid faulty code. This has generated 3 resets of the system by CCG technical staff in order to make it work properly.

5.5 Recommendations relative to Pointe-à-Basile prototype

First, a high frequency electronic modulation system having a duty cycle of 15% should be used to operate the lasers at 15% of their maximum power (in day time). In addition of adjusting the light intensity at the right level for the mariners, this approach would increase the lifetime of the system by a factor of 7. The modulation only need to be fast enough to be perceived as a continuous illumination by the human eye.

Second, the Geneva mechanism appears to work properly. However, the way to couple this mechanism to the shaft on which wedges are mounted must be reviewed. The use of set screw must be avoided or chosen very carefully to eliminate any risk of loosing from vibrations. The use of splined shafts or similar robust coupling techniques is recommended. If any moving mechanical parts can be avoided in the system, then it is recommended to do so since those are always more subject to wearing than fixed parts.

Third, the hole in the rotating wheel for the optical encoder should be made large enough to avoid any faulty operation of the synchronization and consequently of the system.

Fourth, optical parts, ways of mounting them and the type of sealed enclosure could remain the same. However, the diameter of wedges can be reduced from 2" to 1". Mounting windows with an angle on the enclosure is a good way of avoiding dust residues from rain or snow and is recommended. Although heating elements on windows have worked properly is it not sure that condensation of humidity would have been observed without heating elements.

Fifth, from the electrical point of view, all components seem correct, so recommendation is made to keep the last used electronic circuits in function. Those circuits are: laser drivers, power supplies, transient voltage suppresser, Day/Night detector, optical encoder, controlling board. However, items developed but not used in the last electronic circuits, such as the modem and fog detector, should not be used. The use of heaters and fans to condition the temperature of the enclosure is to be evaluated carefully when power consumption is an issue.

Sixth, finally the software, particularly the control of synchronization, should be kept as robust as possible to allow small changes in the timing of codes and to avoid system automatic shut down.

6 Summary of everything that have been learned in the complete laser range light program so far

Here is a summary of what have been learned in the complete laser range light program with emphasis on the Pointe-à-Basile prototype:

- In order to be efficient, compact, and cost effective, future systems must be kept as simple as possible. Unnecessarily options that were included in Pointe-à-Basile prototype were:
    - 11 light codes where 7 would probably have been sufficient
    - Complex fog detection system where on-demand remote intensity boosting would have been more appropriate.
    - Remote control by modem where simple on-site adjustment would be even more effective.
    - Too much laser power for a 15 km channel.
    - Built-in laser detector
- Beam homogenisation should be used in the final system to make intensity uniform across the channel and to avoid misinterpretation of codes by mariners.
- Stray light must also be avoided by taking some precautions in the system design.
- The approach used for the lateral channels shouldn't be used anymore. In this prototype each lateral code was independent from the adjacent one and when an observer was between two codes he saw a random and confusing mix of two mismatched codes. (However the three central channels proved to be efficient since they were synchronized together and because they were produced by two overlapping different colour lasers).
- In all prototypes the laser intensity was conspicuous for the required range on the river and needed to be lowered by 7 times for Day light application in Pointe-à-Basile. Furthermore, the colour of the laser was not changing with fog, rain or snow, and appears to be advantageous against light pollution from urban lights.
- The use of a Day/Night detector allows to adjust laser power to avoid dazzling of mariners at night.
- The wedge scanning mechanism on a rotating shaft has proven to be really appropriate for this application. However, the coupling of Geneva mechanism with the shaft of the system should be replaced by one that would allow a direct fit to the appropriate shaft size (like splined shaft) and that wouldn't use set screws to maintain the shaft in place.
- A simpler and more robust synchronization mechanism or encoder should be used in the future system. This would allow faster rotation of wedges and the system would not stop when shaft rotation speed varies within reasonable range.
- The use of a 3 light codes system (e.g. Hay River prototype) allows small power consumption and the use of solar power supplies. This could also be the case for more light codes but the use of heather for the enclosure should then be avoided or looked at carefully.
- Power adjustment of lasers is required on-site for installation.

- A telescope is also required to align the system properly with respect to the channel.
- When operated at full power the lifetime of lasers is more than one year. However, their lifetime could be extended (for more than 10 years for Pointe-à-Basile's prototype), if they are not used at maximum average power.
- The use of windows with an angle towards the ground and protective shields ensures good protection against rain, snow and dust accumulation.
- The use of heating elements on windows ensures good protection against condensation but an approach with a lower electrical consumption could be considered.
- The use of a transient voltage suppresser revealed to be effective since no failure of the system as been attributed to this kind of problem.
- Future systems must be significantly lighter than the Pointe-à-Basile prototype to allow an easier installation procedure.
- All system components have successfully worked during the one-year test except the mechanical part discussed above that often confused the synchronization system.

7 Suggested solutions to current problems

The results obtained so far from the project are sufficient enough to make the next system the final prototype. If we put together results obtained with the three tested prototypes, all desired characteristics of the Laser Range Lights have been demonstrated but one. Conspicuousness for long ranges has been demonstrated on the St-Michel (1) and Pointe-à-Basile prototypes. Compactness has been demonstrated on prototype 1 and 2 (Hay River). Reliability have been demonstrated on prototype 2 and 3 (except the two set screw of the prototype 3). Good position information in the centre of the channel with the use of only one tower has been demonstrated on the three prototypes. Low power consumption has been demonstrated on the first two prototypes (last prototype has too many options to be as power effective as other prototypes). Easy alignment has been demonstrated in the last two prototypes. Laser signal can be easily distinguished from other light sources.

7.1 Light codes

Actually, the important characteristic that has not been demonstrated yet is the possibility of providing the mariners with good position information on the edges of long maritime channels when more than three codes are required. The solution to this problem can be found in the three central light codes that have already proved to be very efficient in Hay River and Pointe-à-Basile prototypes.

These three codes are actually produced by two laser beams (a red flashing code and a green one) that partially mix in the central part of the channel to produce a third code (an alternatively red and green code). This approach gives easily distinguishable codes because each lateral code by itself can be easily identified and both codes are mixed together in a compatible way to produce a third code in the centre. This way there is no misinterpretation possible from unwanted mix of codes when moving from one point to another within the channel.

To produce more lateral codes to cover lateral parts of the channel, the same kind of partial superimposition of codes can be used. This way, no misinterpretation can be made from code superimposition since this superimposition itself is used to produce more codes. Figure 7.1 illustrates how to produce 7 codes from 4 laser beams. Two different colour laser beams partly superimposed in the centre of the channel, like for the Hay River prototype. While two other laser beams, e.g. one on each side of the channel, partly superimpose to the one of the same colour used in the centre to produce two more codes on each side of the channel. This way each supplemental lateral code produced is of the same colour as the first lateral code on each side of the channel. The duration of the pulse from laser could be adjusted to gives mariners feelings of their position within the channel. For example, small rapidly pulsing codes for the edge of the channel and long pulsing codes nearer the centre of the channel.

There is two possibility of having those four laser beams that provide 7 codes. First possibility would be to use 2 lasers and a rotating mechanism similar to the one use at Pointe-à-Basile. Only one rotating shaft would then be required and with and improved design of the mechanical connection to the shaft reliability should be more than 10 years. However since only 2 laser would be used where four were used before the lifetime of the laser would be reduced. 5 years should be expected for the Pointe-à-Basile site (longer life time for shorter channel length).

Second possibility would be to use four lasers and then their would be no need for any scanning mechanism. This way no moving mechanical part needs to be used. Lasers used to generate ±2 and ±3 codes could be less powerful and then less power consuming, since they are mainly used at shorter range to cover channel edges. This then allows to build a less power consuming system. This approach also allows to increase the lifetime of the system, since lasers are not used on a continuous manner, but rather less than half of the time. The system lifetime would also gain from the fact that no moving mechanical parts would be required. With this approach one can expect to get a system lifetime of approximately 10 years for the longest ranges. Furthermore, since the code sequence would be generated by the software, more flexibility will be possible with respect to this sequence and no problems would arise with respect to the synchronization of this sequence. This could prove to be useful to adapt laser coding to mariners need.

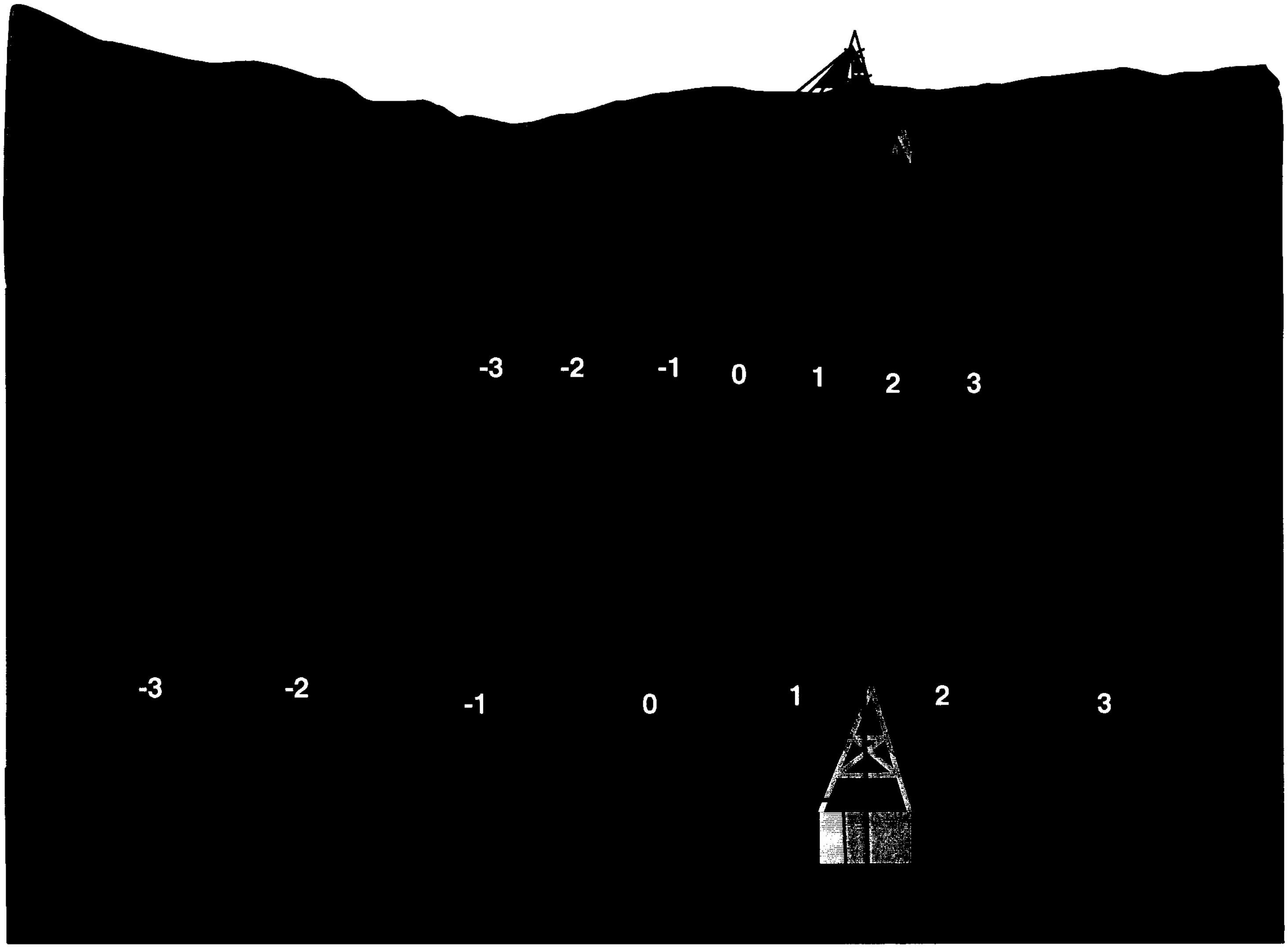


Figure 7.1 : Illustration showing the new proposed code representation (travelling light waves) on the river within buoys.

7.2 Eye safety

Laser range light prototypes tested so far were totally safe for the mariners but for the installers or anyone else located at a few meters from the system possible risks of eye injuries were present. As explained in a former report (INO 01-4069LR R N/A) those possible risks at short distances were due to the high coherence of the laser beams. This coherence makes possible the concentration of high light intensity in a narrow beam (divergences below 0.01 degrees can be obtained easily)

For the laser range light application all that coherence is not needed since the desired divergences range from 0.5 degree to a few degree and a "partial coherence" would be sufficient for that application. This "partial coherence" can be obtained by the insertion of an holographic diffuser in the laser beam. With this beam modification the risk of injury for the bare eyes can be completely eliminated for all distances including for an observer right at the exit of the system.

Figure 7.2 shows the results of the calculations made for the worst case which is a laser beam with enough intensity to be conspicuous at 30 km (power of 130mW, divergence of 0.5 x.0.5 degrees and aperture size of 3cm x 3cm). The eye safety level stated by ANSI standards make the system an intrinsically eye safe system for unaided viewing. With binoculars, the system would be safe for all distance greater than 20 m.

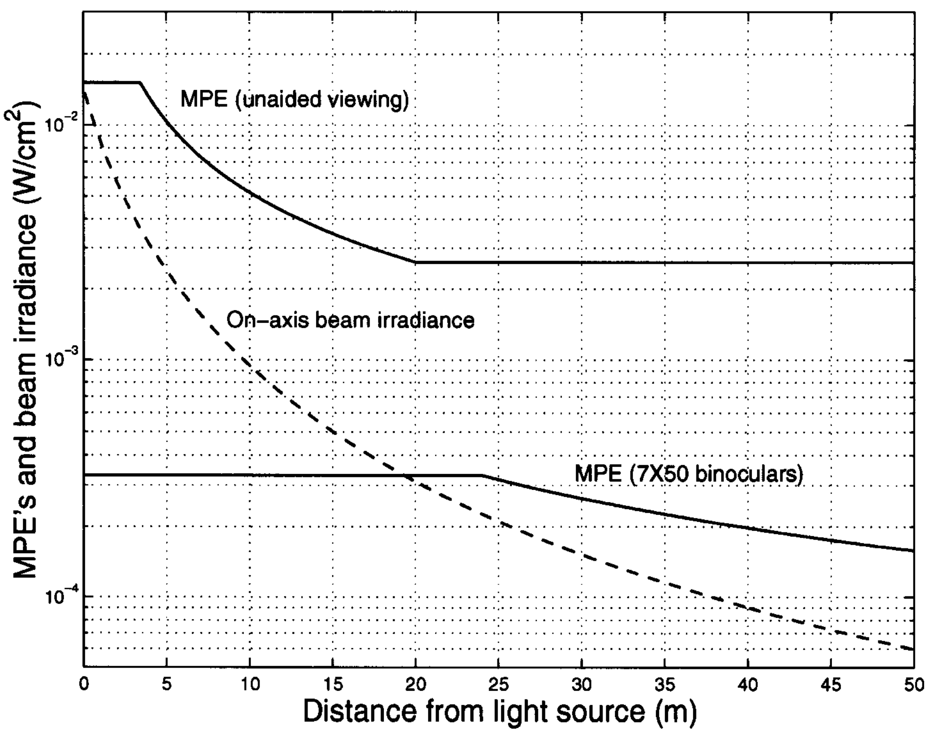


Figure 7.2 : MPE (maximum permissible exposure) levels for unaided viewing and for viewing with 7 x 50 binoculars compared to beam irradiance in the centre of the channel with respect to distance from the system output.

7.3 System dimensions and weight

As mentioned previously all system configuration could be made without any scanning mechanism. This would eliminate the use of motors and thus reduce the system dimensions and weight. The elimination of moving mechanical parts also renders the system more robust with respect to temperature variations and less power consuming. However, for long channels four laser would be required instead of two. The use of heathers and fans inside the system to condition the system temperature could also be eliminated if TEC used to cool lasers can be used as heather when the temperature is very cold and if electronic parts are chosen to work in cold temperature. This would further decrease the power consumption of the system.

7.4 More commercial version

Another characteristic that should be kept is the modular approach used in the design of the Hay River prototype. This approach allows an easy replacement of lasers without having to remove the entire system from the tower. This kind of modular system will also be more compact, lighter and easier to install and maintain. The big and heavy monolithic approach used in the St-Michel and Pointe-à-Basile prototype should not be used in a commercial prototype.

The modular approach will allow to develop only one type of mechanical, electrical, software, and optical setup which should be easy to adapt from one channel configuration to another. This will allow cost reductions by ensuring that design works could be applied to all systems and that scale reduction of costs can be obtained when many modules are produced. Scale reductions will also come from the number of modules produced, since the design will allow the purchase of similar components even for different system types. For high volume (more than 5 systems), a mounting bench could also help to decrease the fabrication, maintenance and repair costs.

8 Proposed characteristics of the final system

Based on the experience acquired during the laser range light program, INO suggests the following characteristics for future systems.

8.1 Other Applications of the laser for Canadian Coast Guard

There are 3 types of system proposed each being modular and all of them looking alike. The first type would be a one laser system used to guide mariners in bad visibility conditions and mainly used as an auxiliary guiding system for the centre of the channel with the use of a remote control (permanent use is also possible). The second type would be composed of two lasers (one red and one green) producing 3 lighting codes (Figure 2.7) and would give some information about the position of the ship within the channel like the Hay River prototype (Figure 2.7). The third type would be composed of 4 laser beams (two red and two green) and would give 7 codes (Figure 7.1) with respect to the position within the channel.

8.2 Design characteristics

The final system would look like illustrations on Figure 8.1. This system will be relatively compact. For a 4 laser beams system the size would be approximately 12" x 24" x 8" without the protective roof, and 14" x 32" x 14" overall. For a 2 lasers system, only 2 exit windows would be required and only one for a one laser system.

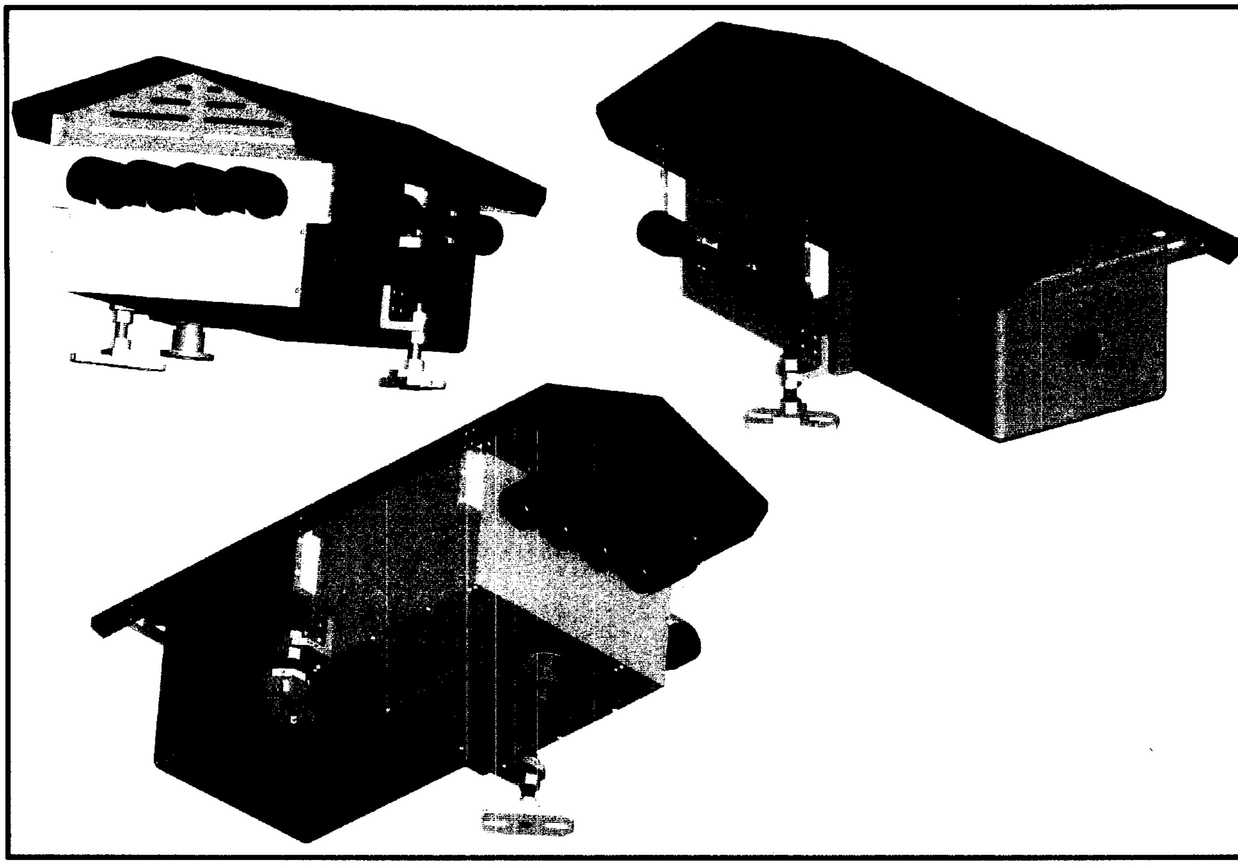


Figure 8.1 : Illustration of the future system at different viewing angles for a 4 laser beams system.

Each proposed system would be composed of 5 modules (Figure 8.2):

1- The **optics or configuration module** which will allow to adapt the optical components to the channel configuration (e.g. length, width, height). It should be noted that this module is the only one that must be custom-made for each site. All other modules will be standard and interchangeable between sites using the same number of laser. This module will be set in lab prior to the system installation since it will contain windows, lens, wedges, and optical holographic diffusers which will need to be placed at precise positions to fit the channel configuration. Holographic diffusers will allow to obtain better uniformity of the intensity across the channel. It will also render the system eye safe as discussed previously. The exit windows will be fixed with an angle toward the ground to eliminate rain, snow, or dust accumulation on them. Small rounded roofs will also be placed on top of windows for same reasons. Since that module doesn't have any component subject to wearing it will be possible to install it permanently in the tower without any need for reinstalling or realigning it. Only the laser and control module (see below) will require special maintenance or repairs.

2- The **protective roof** against rain, sun and snow.

3- The **laser and control module** which will contain lasers, power supplies, Day/Night detector, control electronic board. The transition voltage suppresser would probably be put beside the system itself to make it more compact. Plates used to fix the control module with the configuration module will be made stiff, thick and of thermally conductive material to help eliminate the heat from the control module through the configuration module. This recuperated heat should increase the temperature of the exit windows enough to eliminate humidity condensation on them without the use of a heater.

4- The **alignment module** to align the system with respect to the centre of the channel.

5- The **removable telescope** to help with the proper alignment of the system.

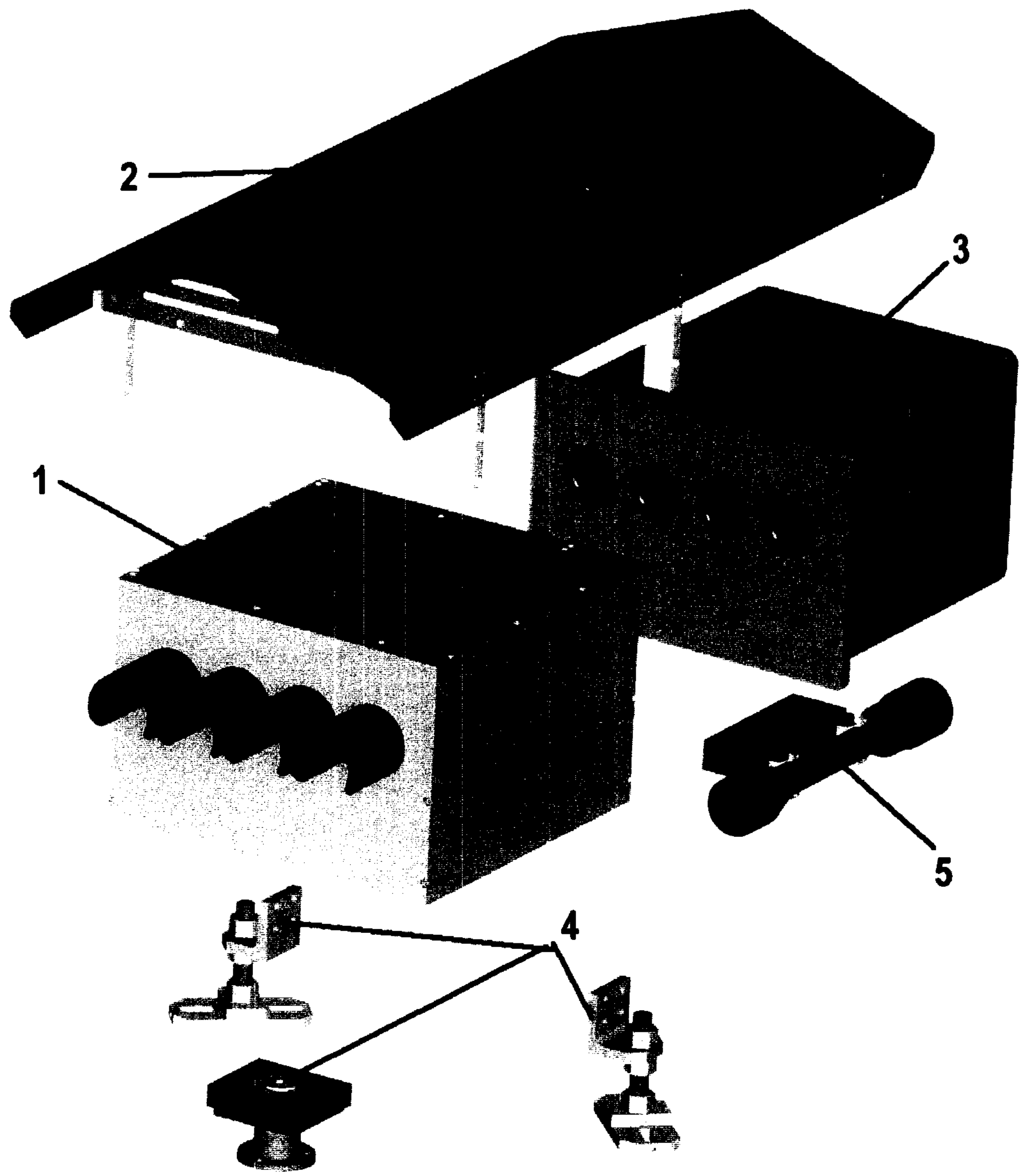


Figure 8.2 : Illustration of the future system modules. 1- optics or configuration module; 2- protective roof; 3- laser and control module; 4- alignment module; 5- removable telescope.

8.3 Installation, maintenance and life expectancy

With respect to installation, the modular approach will ease the transport of the system by making it more compact and lighter in weight, each module weighing less than 50 pounds. The control module will be the most heavy module. The system weight would be approximately 110 pounds overall for a system with 4 lasers. The telescope could be made removable and all modules could be assembled together on-site. The required channel configuration will be taken into account in the configuration module. The required beam divergence and relative positions into the channel will be set in laboratory with the help of proper lens and wedges. This will make the installation easier since only the alignment of the system and the adjustment of the laser power will need to be performed on-site. It should even be possible to perform a pre-setting of the power laser levels prior to installation once the comfort levels are approved by mariners. After this installation, only maintenance will be required.

The control module could be removed from the configuration module without requiring to realign the system. This module can be put upside down on the system, allowing it to adapt to both types of pointing installation (e.g. red colour laser on the left side and green laser on the right side or the reverse) with respect to port side or starboard side. Reference marks placed on configuration and control modules will ensure proper positioning of modules with respect to one another and with the channel configuration. This marking system will allow to use only one backup control module for each one of the 3 system types. This will be made possible from the fact that each configuration module will have input windows placed at the same relative positions and each laser and control module will have exit windows placed to fit these positions. This way, any control module will fit any configuration module of the same number of lasers. In case of the replacement (or maintenance) of a control module, only the laser power settings of the replacement control module will need to be adjusted to fit the configuration of a given channel. The alignment of the system will remain unchanged thanks to the configuration module which will remain in place.

The modular approach will also aim at having a standard set of lasers that will fit all type of systems. Then, a few spare lasers would be sufficient to maintain all types of systems. If the most powerful laser can match the requirement of the most demanding configuration, then its power will only need to be decreased to match configuration requiring less power. This would help to increase the laser lifetime which is expected to be more than 10 years for channel configuration similar to Pointe-à-Basile. The modular approach will also prevent from having to modify the module in the tower when old laser technologies become unavailable. If a laser model become unavailable in the future, only the laser modules will need to be modified without the need to change the system itself.

The system should operate from –40 to +30°C without requiring heater or cooling.

There are no moving mechanical parts in this proposed approach. This will ensure a longer lifetime to the system and reduce its power consumption which should be comparable to the Hay River prototype (e.g. 30W) for a system with 2 lasers. For a system with 4 lasers, the power consumption should be approximately 50 to 60W. The absence of moving mechanical parts will also contribute to reduce the system maintenance such as periodic lubrication or repair of motors.

From what has been learned, the system should require minimal on-site maintenance. For a one year period the Pointe-à-Basile system as not suffer any damage associated to environmental and weather conditions. So, we can expect that for similar conditions there will be no need for shorter than one year period check-up maintenance schedule. The required check-up should then include verification of windows conditions and clean-up for dust accumulation, laser output powers adjustment (keeping track of required adjustments with time should allow replacement of lasers before they fail), alignment module/system stability, and general system condition.

8.4 Costs

The following are preliminary price range estimates (Rough Order of Magnitude – ROM), provided solely at the potential client's demand and does not legally bind INO.

8.4.1 First and subsequent units

For the first type modular system with one red laser, the design and fabrication of the first unit would cost approximately $65,000 CAN and the following ones would cost approximately $25,000 to fabricate. For the third type modular system with four lasers (2 red and 2 green lasers), the design and fabrication of the first unit would cost approximately $160,000 and the following ones would cost approximately $65,000 to fabricate. The second type modular system with 2 lasers (one red and one green) would have costs between prices of these two system types. For more than 5 units of the same system type, it would be possible to reduce the cost per unit further.

8.4.2 Maintenance costs

The major maintenance costs should be the replacement of the lasers every 10 years approximately (more than 10 years for channels shorter than 10 km). Currently the prices of the lasers are 10 k$ for each green laser and 2 k$ for each red laser when ordered by single unit.

The other costs will depend on the approach chosen by the Canadian Coast Guard to maintain the system. For example if replacement laser-and-control-modules are available and if a permanent alignment bench is made to realign new lasers in the modules only a few hours would be required for the complete replacement of the module and the installation of new lasers in the removed module. On the other end, if no replacement and permanent bench are available no expense will be involved before the first replacement of laser. However two visits to the tower would be required by CCG and more time would be required for alignment of the lasers.

8.5 Other possible improvements

Tests have also demonstrated other characteristics that could be implemented in the final prototype. Since tests made at Pointe-à-Basile demonstrated that in good visibility conditions the system has too much power, this available extra power could allow two interesting improvements to the system.

- Beam homogenizers (holographic diffusers) could be implemented in the system. (This device could also make the laser eye safe even at short distances from the system).
- In bad visibility condition, the available extra power could be used when needed to increase the conspicuousness of the system at a level that cannot even be achieved with any other light source. This would make the laser system more attractive to the mariners.

It is also proposed that the system is kept as simple as possible and options like visibility (or fog) detector and modem communication unit could be suppressed unless explicitly required by users.

9 Conclusion

From comments collected from mariners, it appears that some (not to say many) of them are either sceptical or have poor perception of laser range lights used in this program. Two reasons could explain this perception. First, the power level of lasers on the river were too strong at first and comments from mariners suggest that they were stressed about eye safety issues. Second, laser codes in sub-channels were confusing while mariners use actual standard range lights on a more intuitive manner. The next step should take into account mariners involvement to gain their trust and to ensure the success of the continuity of this program. To improve their confidence in this kind of system, one good approach would be to first use a one colour system that would be used in the centre of the channel. The laser could be lighted on by mariners with the help of a remote control when fog or bad weather conditions prevailed on the channel. Once the confidence of mariners towards laser range light and their involvement would be high enough, more evolved laser range light codes could be proposed, fabricated, and installed.

Here are the proposed steps to make the next prototype a final prototype:

1. Design meetings with INO, Canadian Coast Guard and the mariners to select the light codes and the angular distributions (variable angles are possible) of the beams that best fit user's needs and that can be produce in a commercial unit. Decision should be taken also concerning the way extra power of the system should be used. A software developed by INO is now available to simulate light codes on a computer. This software could help in selecting the code that best fit mariners needs.
2. A survey of all sites that would benefit from a laser range as well as a classification of these sites by Canadian Coast Guard and INO in order to define the characteristics of the laser range required for each site.
3. Identification of what is the category of site the laser range should address first.
4. Design of the system by INO.

5. Design review meeting with INO, Canadian Coast Guard and the mariners to verify if the proposed design (especially the sub-channel light coding) fits the actual needs.
6. Design modifications to take into account changes proposed in the design review meeting.
7. Fabrication of the system at INO.
8. Complete testing of the system at INO.
9. Installation of the system on the chosen site and adjustment of:
   - Alignment
   - Power level of each laser by day
   - Power level of each laser by night
   - Adjustment of transition between day and night
10. Data collection from mariners and technical staff about their appreciation to validate the system performance.
11. Adjustment (fine tuning) of light codings from mariners comments.

These steps are a rather straightforward and standard approach for the development of a final prototype. In these steps, the importance of meetings should not be underestimated.

We have to consider that nothing at the technical level should prevent the fabrication of a final prototype that fits well the actual needs of the Canadian Coast Guard. Previous tests have proven that lasers, optics and electronics needed for the development of laser range are already available. In order to make the final prototype almost identical to the future commercial version, more investment in the design of the system is now needed to provide modular systems which would be easier to install and maintain. This design will involve comments from many people, but it is worth collecting them before the system is fabricated.

Since first laser-range-light prototype was installed at St-Michel-de-Bellechasse in December of 1995, several things have been learned on the application of laser technologies to maritime applications. Several problems were encountered during the development; solutions have been found and successfully tested for all encountered problems but one. The important characteristic that has not been demonstrated yet is the possibility of providing the mariners with good position information on the edges of long maritime channels. The solution to this problem can be found in the three central light codes that have already proven to be very efficient in Hay River and Pointe-à-Basile prototype.

Besides the advantage of cost reduction anticipated by Canadian Coast Guard, laser range lights have two advantages that should be appreciated by the mariners. First, the extra power they give could be used in bad visibility conditions to provide the mariners with position information they never had before. Second, in areas where the standard range light may be confused with urban light, laser range would be easier to distinguish from other light sources.

All required components are now available to build compact and efficient laser range lights for any maritime sites. A good light coding still needs to be found for long channels. Mariners should participate in the design of the lighting code in order to fulfil their needs. The replacement of standard range lights by laser range lights will modify the way position information is provided to mariners. Making the mariners part of the design process will allow for the development of a code that will make the transition process easier and a more efficient code.