ME 218b Winter 2019: The Great Pacific Garbage Patch Swirl Baby Swirl!

Project Preview on March 2 from 1-5 pm.
Grading Period begins March 2 , and runs through 11:59 pm on March 5.
Project Presentation on March 6 starting at 7:00 pm.

Goal:

The goal of this project is to provide you with an opportunity to apply your knowledge to solve an open-ended problem. The task is to design and build a machine that can autonomously navigate the ocean and successfully clean up marine debris.

Purpose:

The underlying purpose of this project is to give you some experience in integrating all that you have learned in ME218 as well as your prior courses. To gain this experience, you will design and implement an autonomous mobile robot that can compete in a game of speed, skill and strategy against machines constructed by other teams from the class.

Background:

While individual efforts are critical to reduce the magnitude of the problem and keep awareness high, systemic interventions are needed to make impacts at a large enough scale and fast enough speed.

The Ocean Cleanup, a non-governmental environmental organization based in the Netherlands, has been attempting one such project: collecting plastics and other trash from the Great Pacific Garbage Patch. Their device has been at sea since September, in the first large-scale trial of their technology. Unfortunately, they've suffered a setback; early this year, the large boom which supports their collection net broke, requiring the entire apparatus to be towed back to shore for repairs.[1]

While the CEO of The Ocean Cleanup, Boyan Slat, is confident that the system will be operational by the end of 2019, he's also covering his bases by recruiting you, ME218, to design alternate systems in case something more effective is possible. Your task is to build a Big Autonomous Recycling-Garbage Extractor (BARGE), and demonstrate the ability to autonomously navigate, collect Gunk and Refuse which is Randomly Bobbing And Getting Everywhere (GARBAGEs[2]), and appropriately deliver them to be trashed or recycled. The designs will be tested against one another to find the one that is the best at collecting GARBAGEs, and that design will then be evaluated for further development.

The Task:

Your BARGEs will be operating on the field located in the SPDL, and then competing against each other on the same field after it has been moved to the Atrium of Bldg. 550 (our classroom building) during the public presentations.

> *We need to solve the climate crisis, it's not a political issue, it's a moral issue. We have everything we need to get started, with the possible exception of the will to act, that's a renewable resource, let's renew it.*
>
> *Al Gore*

Specifications

The Ocean:

- ☐ The ocean is an approximately 8 × 8 ft area with exterior walls 3.5 in tall. A top view is shown in Figure 1.
- ☐ The ocean will be covered by a 1/8" thick PETG protective sheet.
- ☐ The landfills are located near two opposing corners of the ocean (North, South).
- ☐ Each landfill has a modulated IR beacon mounted above it, with the emitters located 13" above the surface of the ocean.

[1] Nagourney, Eric. "Ocean Cleanup Plastic Collector Heading Home. In Pieces." *The New York Times* 3 Jan. 2019: Online.
[2] Remember that this is an acronym. *The New York Times* has addressed this in the past. This is how you pluralize an acronym.

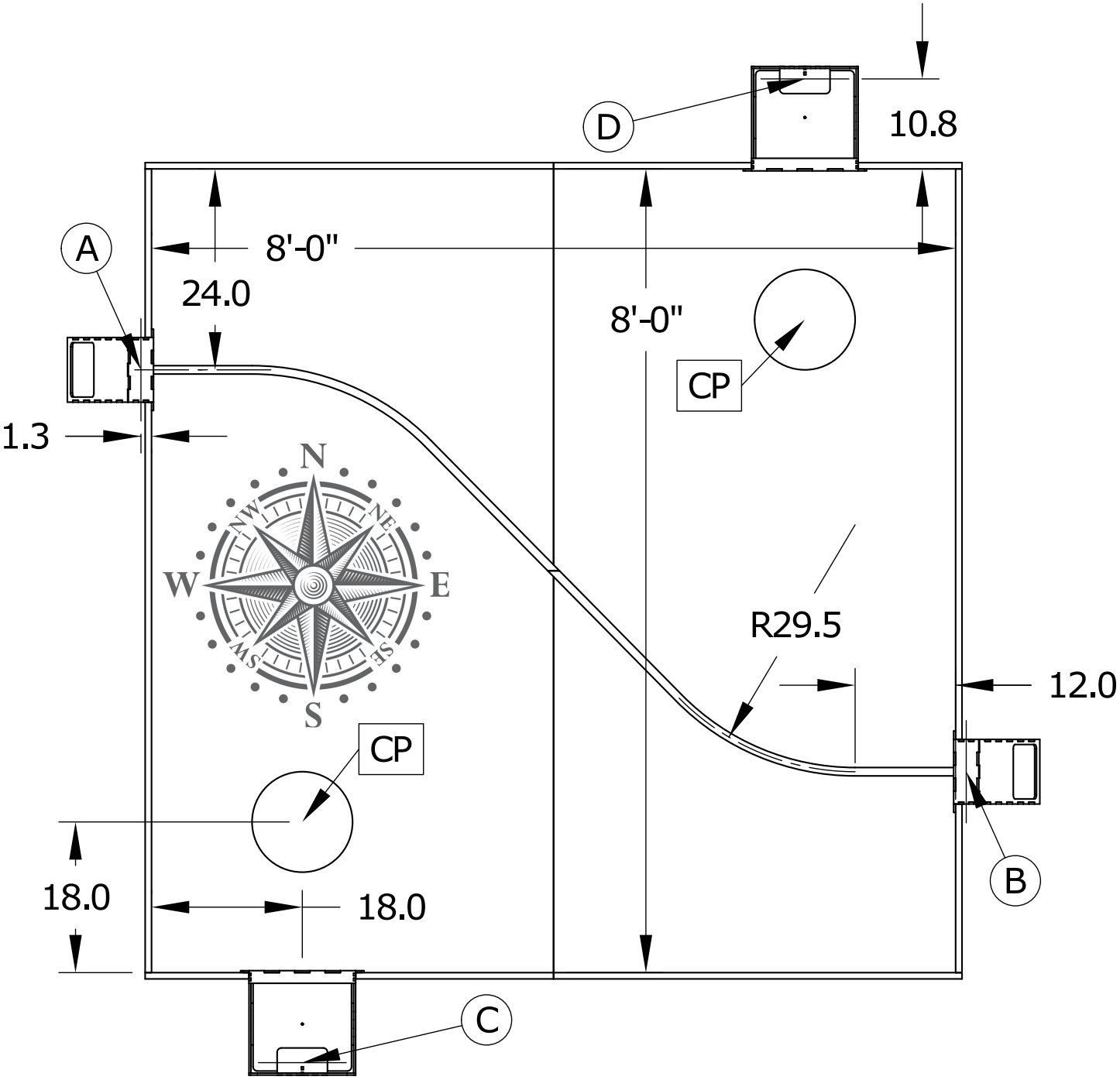

Figure 1: The ocean. Landfills are at the southwest and northeast corners. Recycling centers are located on the east and west walls. Each trash location carries a beacon, marked as A–D. See Table 1 for beacon frequencies.

Beacon	ID	Frequency
West Recycling	A	1.667 kHz
East Recycling	B	2.000 kHz
South Landfill	C	1.429 kHz
North Landfill	D	1.250 kHz

Table 1: Beacon Modulation Frequencies.

- ☐ The recycling centers are located on opposite sides of the ocean (East, West).
- ☐ Each recycling center has a modulated IR beacon mounted above it, with the emitters located 13” above the surface of the ocean.
- ☐ The North Team landfill beacon emits IR modulated with a period of 800 µs.
- ☐ The South Team landfill beacon emits IR modulated with a period of 700 µs.
- ☐ The beacon on the West recycling center emits IR modulated with a period of 600 µs.
- ☐ The beacon on the East recycling center emits IR modulated with a period of 500 µs.
- ☐ The Recycling Centers will be connected by a 1” black tape line, as shown in Figure 1. Beneath the black tape will be a wire carrying a 100 mA current modulated at a frequency of 20 kHz.
- ☐ The four winds[3] will blow to create a circular air current at the level of the ocean.
- ☐ There are two catch points[4] on the ocean, each 1 foot in diameter. Each catch point is centered with respect to the nearest landfill, and located 18” directly into the ocean. These are marked as CP in Figure 1, and included for reference. They will not actually be marked on the ocean.

The BARGE:

- ☐ Your BARGE must be a stand-alone entity, capable of meeting all specifications described in this document. Only NiCd/NiMH battery power is allowed. No more than two 7.2 V batteries may be used to drive the motors that transfer force to the ground.
- ☐ Each BARGE must have a mechanism to designate the BARGE as North Team or South Team.
- ☐ Each BARGE must include a means to clearly indicate to the audience its North Team/South Team status.
- ☐ BARGEs must be autonomous and untethered.
- ☐ The only parts of the BARGE that may ever touch the playing surface are wheels, ball casters, or slippery supports used to balance the BARGE.
- ☐ Only the supplied motors may be used to drive anything that transfers force to the ground.
- ☐ There must be a bumper surrounding the perimeter of your BARGE extending for at least 2” vertically, and must fully cover the region between 2.5” and 3.5” ($\pm$ 1/8”) from the floor.
- ☐ The bumper must be covered in a retroreflective tape provided to you by SPDL.
- ☐ The bumper and the retroreflective tape must be uninterrupted within the region between 2.5” and 3.5” from the floor.
- ☐ Your BARGE must be fully contained within a 1’ cube at the beginning of the game and never expand horizontally beyond the perimeter defined at the beginning of the game.
- ☐ If your BARGE chooses to launch GARBAGEs, they must be launched either horizontally at floor level or with a substantially above-horizontal trajectory. In either case, the GARBAGE may land no more than 9’

[3] That is, fans. The intent is to create a clockwise circulation of GARBAGEs; note that the implementation may vary.
[4] See the section detailing the game for details on the function of these regions.

from the BARGE and reach a peak height of no more than 8' above the floor of the playing field.

- ☐ Each BARGE must carry an easily accessible switch which shall cut power to the BARGE in case of a software or hardware malfunction.
- ☐ Each BARGE must be constructed as part of ME218b. It may not be based on a commercial or otherwise preexisting platform.
- ☐ Any exterior corners on the BARGE must have a radius of at least 1/2".
- ☐ Due to EPA budget cuts, you are limited to an expenditure of **$220.00/team** for all materials and parts used in the construction of your project. Materials from the lab kit or the Cabinet Of Freedom do not count against the limit, all other items count at their fair market value.
- ☐ Each BARGE must provide a clearly visible indicator when it thinks that the game is in progress. This indicator should be activated when the BARGE determines that a game has started and be deactivated when the game status indicates the end of the game.

The Landfills:

- ☐ Each team will have an assigned landfill; all GARBAGEs which are in the North landfill will be counted for North Team, and similarly for the South landfill and South Team.
- ☐ Each landfill will have two openings for accepting GARBAGEs. Dimensioned and isometric views of a landfill are presented in Figure 2.
- ☐ The first of these openings will be at floor level, and measures 12" in width and 2.2" in height.
- ☐ The second opening opens upwards, is 3.5" above the playing surface, and has an area of 12.2" in width and 10.7" in depth.
- ☐ This second opening has a backboard extending to 14" above the playing surface. The IR beacon is attached to this backboard.
- ☐ The landfills will measure the total weight of GARBAGEs in the landfill; only GARBAGEs that enter and stay in a landfill will be weighed.

The Recycling Centers:

- ☐ Figure 3 shows dimensioned and isometric views of a recycling center.
- ☐ In order for the recycling center to accept GARBAGEs, the BARGE must provide a continuous IR signal modulated at its assigned frequency.
- ☐ The IR receiver on the recycling center will be located 6" above the surface of the ocean and centered on the width of the recycling center.
- ☐ GARBAGEs must be delivered to the recycling center through the aperture at floor level shown in Fig. 3.

The COMPASS:

- ☐ The Competition Overview Module with Points and Synchronization System (COMPASS) will provide information to the BARGE about the status of the game.
- ☐ The COMPASS will communicate with your BARGE over a 4-wire SPI bus.
- ☐ The COMPASS will be recognized by and communicate wirelessly with the ocean, so it should be mounted where it will have good radio reception.
- ☐ A complete description of the COMPASS, from both an electrical and protocol standpoint, is included in an appendix that accompanies this project description.

The Game:

- ☐ The game is a head-to-head contest between two BARGEs as they attempt to clean up the ocean by properly disposing GARBAGEs into landfills or recycling centers.

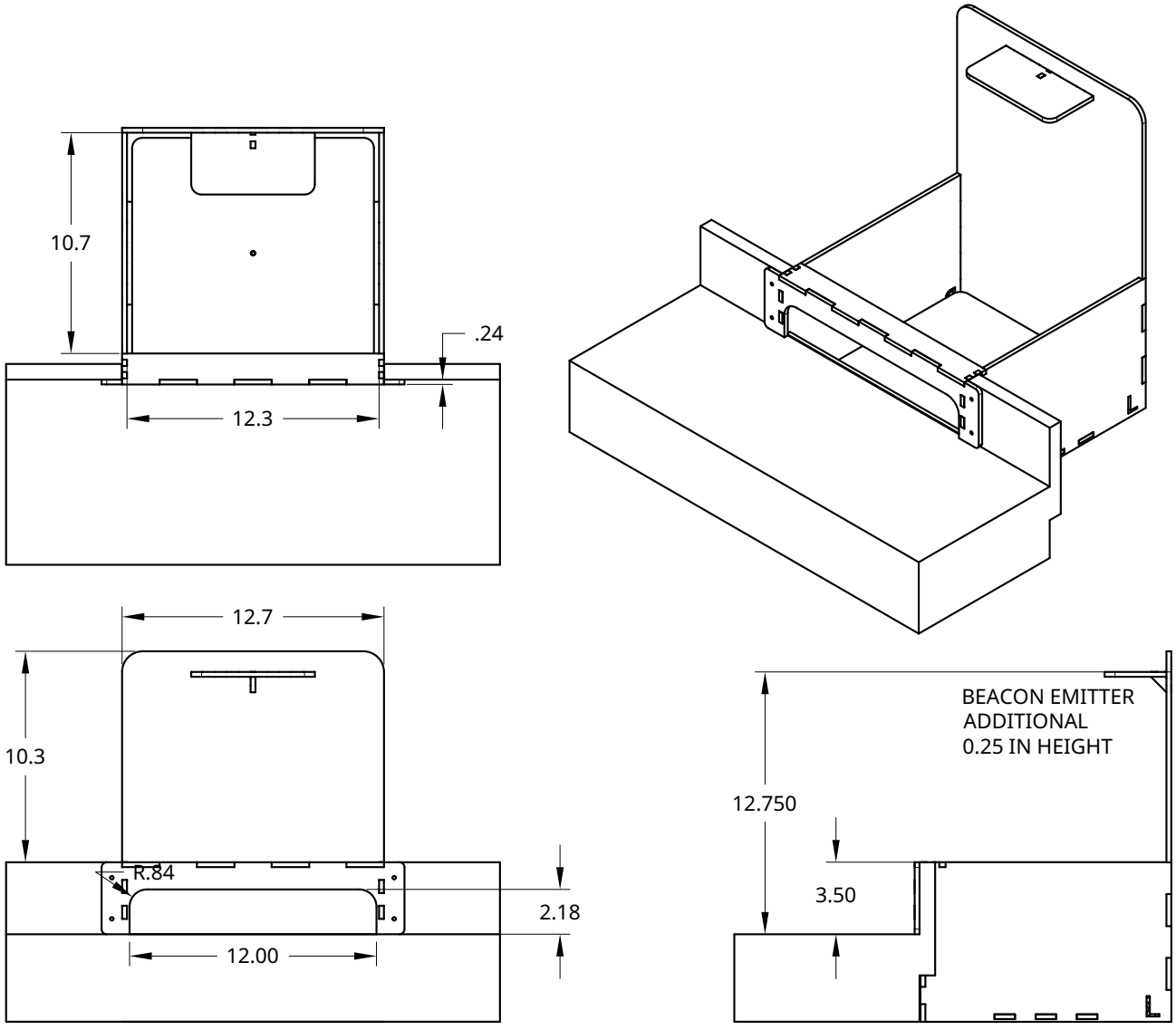

Figure 2: The landfill.

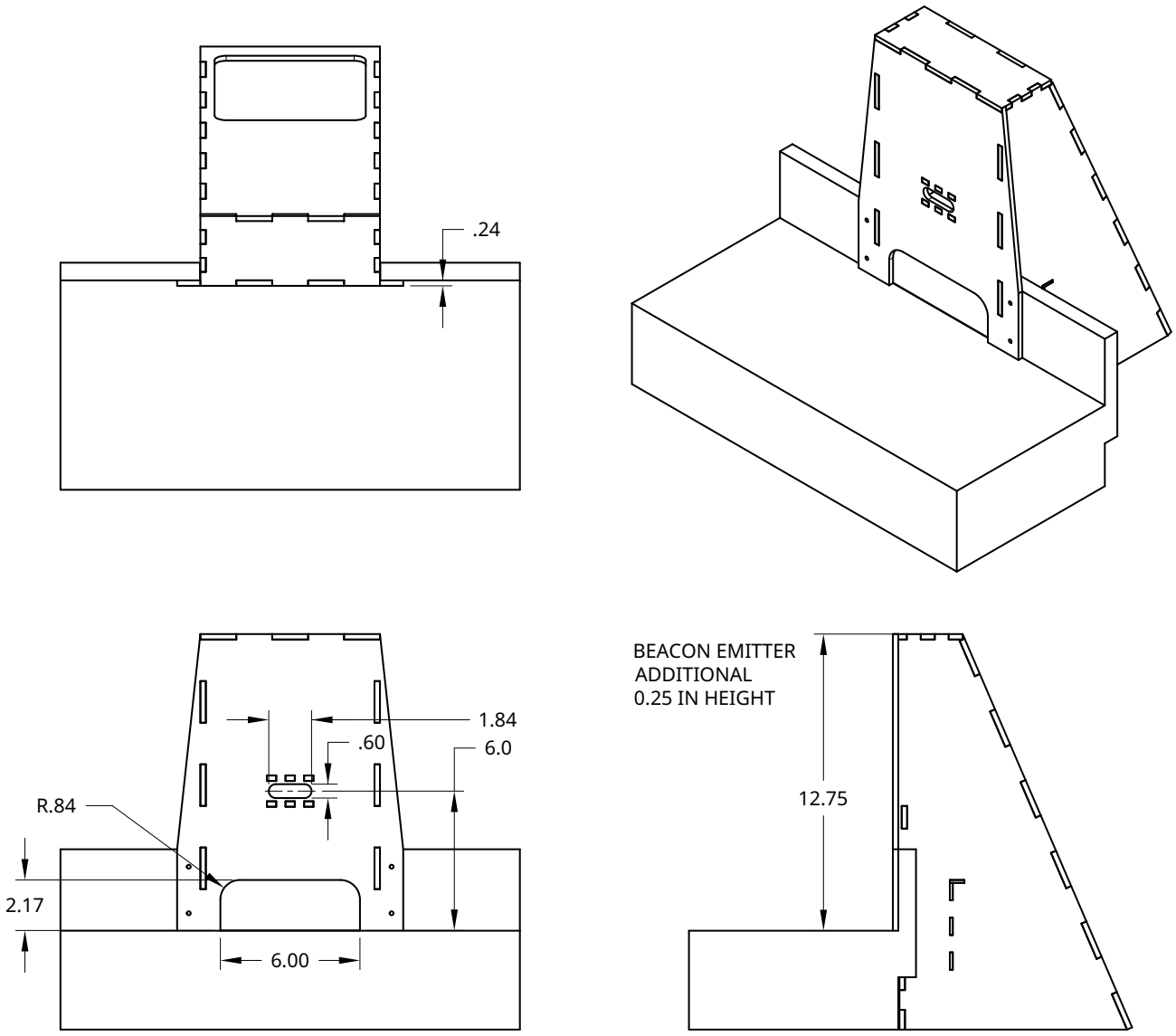

Figure 3: The reload station.

- ☐ Each game will last for 2 minutes, 18 seconds.
- ☐ At the end of 2:18, the BARGE which most successfully cleaned up the ocean (as measured by eco-points) is the winner.
- ☐ At the beginning of the game, the North Team BARGE will be placed somewhere on the ocean North of the tape line by a member of the teaching staff.
- ☐ At the beginning of the game, the South Team BARGE will be placed somewhere on the ocean South of the tape line by a member of the teaching staff.
- ☐ The game will begin when a query to the COMPASS indicates that the game state has changed from "Waiting for Start" to "Cleaning Up".
- ☐ Any GARBAGE may be deposited into a landfill. Trash is a bulk commodity, and so will earn eco-points at a rate of 1 point per 3 grams. Keep in mind that the landfills are assigned to a team.[5]
- ☐ Each BARGE will be randomly assigned a color of GARBAGE which it may recycle, as well as a frequency code to activate a Recycling Center. These colors and frequencies are guaranteed to be different for each team in a given game.
- ☐ During the course of the game, additional GARBAGEs will be shot onto the two catch points on the field. These GARBAGEs will land with a trajectory near vertical.
- ☐ The additional GARBAGEs which are shot onto the catch points will always be blue; Recycling Centers will treat these GARBAGEs as matching your BARGE's assigned color. Thus, either team may recycle these GARBAGEs, but only at the recycling center which is accepting that team's assigned color.
- ☐ At any given point during the game, each Recycling Center will accept only one team's color of GARBAGE. A BARGE may only recycle at the Recycling Center which is currently accepting its assigned color.
- ☐ During the game, the color accepted by each Recycling Center may change, though at any point it will be guaranteed that one Recycling Center is accepting each team's assigned color. The color of GARBAGEs that is being accepted by the Recycling Centers may be requested from the COMPASS.
- ☐ Successfully recycling a GARBAGE will earn a BARGE some number of eco-points, as defined in the recycling value information from the COMPASS. This value will be at least ten (10) eco-points, but may be higher. During a given game, the value for successfully recycling a GARBAGE will remain constant.
- ☐ Incorrectly putting trash into a Recycling Center will result in that BARGE being assessed a fine of one-half of the recycling value.[6]
- ☐ If the score is tied at the end of the 2:18 regulation time, the BARGE which scored the most eco-points via the recycling centers will win the game. If the score is still tied when taking into account eco-points from recycling, the game will be decided by an extremely dramatic coin flip.
- ☐ When the clock expires, the game state will change to "Game Over". At this point your BARGE must cease attempting to score eco-points.

Rules:

- ☐ No solderless breadboards are permitted in the final project.
- ☐ A BARGE that makes contact with another BARGE must move away from the contact. Incidental contact will not be penalized, but persistent contact of more than three seconds with another BARGE will result in an assessed penalty of eco-points equal to half of the value of a recycled GARBAGE.
- ☐ Intentional interference with the operation of another BARGE is prohibited.
- ☐ Each BARGE must start and remain in once piece during the round. Any locomotion of the BARGE should

[5] That is, the South Team BARGE is permitted to deposit GARBAGEs into the North Landfill, but this will result in eco-points being awarded to North Team. This will likely also result in much hilarity at South Team's expense.

[6] For example, if recycling is worth 26 points, each piece of trash placed in a recycling center will result in a loss of 13 eco-points for that BARGE.

cause all parts of the BARGE to move.

- ☐ Your BARGE may not **IN ANY WAY** alter the condition (e.g. mar the walls or the floor) of the playing field or the foam balls. Before you choose your wheel material and again before you place your robot on the field for the first time, borrow a material sample from the TAs and test to be sure that your wheels will not mar the floor material.
- ☐ Intentional jamming of your opponent's senses or violation of the communications protocol is prohibited.
- ☐ Any IR emission from your BARGE **MUST** be confined to the volume within 7" of the surface of the ocean.
- ☐ Your BARGE may not present obstructions to the IR beacon within the volume between 12" and 14" above the playing field.
- ☐ All projects must respect the spirit of the rules. If your team is considering anything that may violate the spirit of the rules, you must consult a member of the teaching staff.

Safety:

- ☐ The BARGE should be safe, both to the user and the spectators. The teaching staff reserves the right to disqualify any BARGE considered unsafe. This also applies during testing, so keep the BARGE velocity and shooting velocity low enough so as not to cause problems.
- ☐ BARGEs must be stable in the presence of a 30 mph wind.
- ☐ No part of the machine may become ballistic. The foam balls are not actually part of your machines.
- ☐ All liquids, gels, and aerosols must be in three-ounce or smaller containers. All liquids, gels, and aerosols must be placed in a single, quart-size, zip-top, clear plastic bag. Each BARGE can use only one, quart-size, zip-top, clear plastic bag.
- ☐ Red, Green, and Blue shells are prohibited. Any banana peels must stay within the confines of your BARGE at all times.
- ☐ Any early celebrations will be penalized.
- ☐ Your BARGE is not permitted to steal talent from any other BARGEs.
- ☐ BARGEs may alter the space-time continuum only during the public presentations.

Checkpoints

Design Review:

During the day on **February 12** we will conduct design reviews. Sign-ups for the hour-long slots for 4 teams will happen via a Google Sheet. Each group should prepare a few **simple** PowerPoint slides (scans of sketches are OK). **No code, no state diagrams, no circuits.** The focus should be on the overall design and how you are tackling what you think are the critical subsystems. One member of the team must bring a laptop and any necessary adapters to produce a VGA or HDMI video signal to be used in connecting to the screen for your presentation. You will present these to other members of the class, members of the teaching staff and coaches so that all may hear about your ideas and provide feedback and advice.

How appropriate to call this planet Earth when it is quite clearly ocean.

Arthur C. Clarke

First Checkpoint:

On **2/14/19**, you will turn in a system block diagram, a set of Altium schematics, textual descriptions and software design documentation (including refined state chart) that describes the state of the design *at that point in time*. The designs need not be tested at this point, but must include designs to address all of the major subsystems. For your submission to GradeScope, create a single PDF document that includes the system block diagram, an Altium schematic, your refined state charts, and a document describing, in words, your strategy for meeting the project requirements and identifying your robot's core functionality. Only one team member needs to submit your checkpoint documentation.

Water and air, the two essential fluids on which all life depends, have become global garbage cans.

Jacques Yves Cousteau

Second Checkpoint:

On **2/19/19**, you must demonstrate your untethered, motorized platform moving under autonomous software control. Your platform must be able to drive across the ocean and back under software control.

The least movement is of importance to all nature. The entire ocean is affected by a pebble.

Blaise Pascal

Third Checkpoint:

On **2/22/19**, you must demonstrate the integration of the COMPASS with your mobile platform and the ability of your BARGE to communicate with the COMPASS to exercise all of the COMPASS's capabilities. Evidence of achieving this functionality will be demonstrated by your BARGE initiating motion based on the game status information from the COMPASS changing from "Waiting for Start" to "Cleaning Up".

Drinking your own blood is the paradigm of recycling.

Gary Busey

Fourth Checkpoint:

On **2/26/19**, you must demonstrate your robot's ability to

1. Start navigating upon the game status changing from "waiting" to "clean up".
2. Collect a GARBAGE.
3. Navigate to the recycling center.
4. Communicate with the recycling center to open it.

It is the worst of times but it is the best of times because we still have a chance.

Sylvia Earle

Project Preview:

At the Project Preview on **3/2/19**, each BARGE must demonstrate, in an integrated form,

1. The ability to move around the ocean under software control.
2. The ability to communicate with the COMPASS.
3. The ability to collect a GARBAGE.
4. The ability to open a recycling center.
5. The ability to back away on contact with another BARGE.

This will be tested by communicating a "Cleaning Up" status followed by the BARGE proceeding to navigate around the field, collecting a GARBAGE, and communicating with the recycling center. At some point during this sequence, your BARGE will encounter a standard SPDL-prepared opponent, and must demonstrate the ability to back away in the case of contact between your BARGE and the opponent.

The plastic in the ocean is not going to go away by itself. It's not a hopeful situation if the only thing you can do is not make it worse.

Boyan Slat

Grading:

The grading period will open on **3/2/19** and will remain open until 11:59 pm on **3/5/19**.

During a grading round, each BARGE will be required to demonstrate a complete game. The evaluation will take place with only a single BARGE on the field, competing and scoring in a match against a static dummy. During the match, your BARGE must demonstrate all abilities detailed in the Project Preview specification, with the addition of scoring by successfully depositing a GARBAGE into either landfill or recycling.

Evaluation for grading purposes will only occur during these rounds. If your BARGE fails at its first attempt to demonstrate its ability, it must then demonstrate the ability two times in succession at its next attempt. These increases continue after repeated failed attempts to a maximum of 4 required successive demonstrations.

There is no such thing as "away". When we throw anything away it must go somewhere.

Annie Leonard

Public Presentation:

This will take place on **3/6/19** starting at **7:00 pm** in the Atrium of Building 550.

We know that when we protect our oceans we're protecting our future.

Bill Clinton

Report:

Draft due on **3/11/19** by 4:00 pm. The final version with revisions is due by 5:00 pm on **3/15/19**.

The sea, though changed in a sinister way, will continue to exist: the threat is rather to life itself.

Rachel Carson

Evaluation

Performance Testing Procedures:

One or more team members will operate the BARGE during the performance evaluation. A competition among the class' BARGEs will take place after the performance evaluation.

Performance Evaluation:

Performance evaluation will take place twice during the project duration, at the Project Preview and at the Grading Session. Everyone will participate at this level.

The Competition:

On the night of the public presentations, a tournament will be held. **Performance during the tournament has no impact on your grade.**

Grading Criteria:

- ☐ **Concept (10 %)** This will be based on the technical merit of the design and coding for the machine. Included in this grade will be evaluation of the appropriateness of the solution, as well as innovative hardware, software and use of physical principles in the solution.
- ☐ **Implementation (15 %)** This will be based on the prototype displayed at the evaluation session. Included in this grade will be evaluation of the physical appearance of the prototype and quality of construction. We will concentrate heavily on craftsmanship and finished appearance.
- ☐ **Checkpoint Performance (10 %)** Based on demonstrating the required functionality at the **checkpoints**.
- ☐ **Preliminary Performance (10 %)** Based on the results of the performance testing during the **Project Preview**.
- ☐ **Performance (20 %)** Based on the results of the performance testing during the **Grading Session**.
- ☐ **Coaches' Evaluation (5 %)** Evaluation by your coach: did you make use of their input before the design review and during the course of the project.
- ☐ **Report (20 %)** This will be based on an evaluation of the written report. It will be judged on clarity of explanations, completeness and appropriateness of the documentation. The report should be in the form of a stand-alone web site and must include schematics, pseudo-code, state charts, header & code listings, dimensioned sketches/drawings showing relative scale, a complete Bill-of-Materials (BOM) for the project as well as a 1 page description of function and a "Gems of Wisdom for future generations of 218ers" page.

  To submit your report you must **include a text file with the URL to your site** and place that file into the Reports folder of one of the team members. The only file types in your final report should be HTML (including style sheets if you choose), JPEG or other viewable image files and PDF files. Schematics should be PDF files, not bitmaps (PNG, JPEG, GIF, etc.). A reasonable resolution bitmap place-holder with a link to a PDF is the best solution to readability. Do not simply place a link to the PDF of the schematic without a viewable preview on the web page. Do not include `.doc`, `.docx`, `.xls`, `.xlsx` or other files that require opening a separate application outside of the browser. **Do not embed video files directly** into your site. If you want to include video, link to YouTube or other video sharing site.

It is critical that the text file with the URL of your report be in the Reports folder on time so that the peer reviewing team will have an adequate opportunity to review it before class the following day. Final versions of the reports, incorporating the review comments are due (again, as a text file with an updated (even if it didn't change) URL) by 5:00 pm on 3/15/19 in the Reports folder from one of the team members. Make sure to test all of your links before submitting. If we can't simply open the link and read it on our machines, then we can't grade it.

- ☐ **Report Review (10 %)** These points will be awarded based on the thoroughness of your review of your partner team's report. Read the explanations, do they make sense? Review the circuits, do they look like they should work? Could this BARGE realistically be built for $220? If, during grading, we find things that don't make sense or circuits that won't work we will consult your review. If the review caught them, then the team will lose points on their report. If the reviewers missed it, then they will lose points for their review. The report review should submitted be in the form of a word document that you place into one of your team members folders by 4:00 pm on 3/12/19.
- ☐ **Housekeeping** Based on the timely return of SPDL components, cleanliness of group workstations as well as the overall cleanliness of the lab. No grades will be recorded for teams that have not returned or paid replacement costs for the items borrowed from the SPDL, including but not limited to the Tiva, power supplies, logic analyzer, tools, etc.

Team Organization

While it may be tempting (as more efficient) to organize your teams around specialists who handle, for example, communications, sensing, motion, etc. I believe that in the long run this will be a mistake. I have heard from many 218 alumni who did this and reported that they were sad that they had because they didn't get, for example, communications experience. I would like to encourage you to remember that, first and foremost, the purpose of the project is to enhance your learning of the material. An organization that deeply involves all of the team members in the details of the design, implementation and debugging of all subsystems will not only provide a better learning experience, it will also prevent you from getting hung up during the integration and testing phase because the "expert" on that subsystem is not available.

Mechanical Design and Robustness

Your machine must be rugged enough to survive your testing as well as competing against another robot.

While the emphasis in the lecture has concentrated on the electronics and software, don't forget the mechanical aspect. Historically, project failures are often due to poor mechanical design or implementation. Pay attention to craftsmanship, and put thought into how your design supports all of the loads your robot will be subject to—not just when it's operating as intended, but also when it receives bumps from other robots on the field.

While we have focused largely on software implementation details in class, keep in mind that although computers are deterministic, the real world is not.[7] Make sure your software is built not just to handle what you hope will happen, but also everything you think might happen that could cause you problems.

Preventing Disaster

It is unlikely, even given the advice in the paragraph above, that your robot will be robust to a fall from the table-top to the floor. To avoid the possibility of that happening, you should create a stand/platform for your 'bot that it can sit on with its wheels not touching the table-top. With this stand in place and your robot perched upon it whenever it is on the bench-top, even if your code or hardware goes haywire and starts the wheels spinning unexpectedly , those spinning wheels will not drive your 'bot off the bench-top.

[7] Well, at small length scales. But in this case, you don't have enough information on the details of your robot's interaction with the world to treat it as deterministic, so don't.

Resources

Websites:

SparkFun	Seeed Studio	Jameco	Mouser
Newark	Ponoko	Adafruit	Hackaday
DigiKey	McMaster-Carr	HobbyKing	ServoCity

You may also find PlantUML and PlantText helpful for creating message sequence diagrams or system diagrams.

Local Stores:

J&M Hobby House in San Carlos
Jameco in Belmont
TAP Plastics in Mountain View

Gems of Wisdom:

Be sure to check out The ME218 Archive for guidance from past generations.

ME 218b Winter 2019: COMPASS Protocol Definition

Revision 1: 2/6/19

Purpose:

The primary purpose of the Competition Overview Module with Points and Synchronization System (COMPASS) is to act as a gateway to the field infrastructure to allow your BARGE to request information about the state of the game.

Connection Interface

Connector:

The connector of the COMPASS is a 6-pin keyed Molex connector.

Pinout:

Pin	Name	Function
1	V_{dd}	Power to the COMPASS; 3.3 V @ 100 mA
2	SDI	Serial Data Into the COMPASS
3	SDO	Serial Data Out of the COMPASS
4	SCK	Serial clock
5	SS	Slave select; active low, has on-board pull-up to 3.3 V
6	GND	Ground reference for the COMPASS

Electrical Specifications

Parameter	Min	Max	Unit
V_{IH}	$0.65V_{dd}$		V
V_{OH}	$V_{dd} - 0.4$		V
V_{IL}		$0.35V_{dd}$	V
V_{OL}		0.4	V
I_{IH}, I_{IL}		± 1	µA
I_{OH}	-20		µA
I_{OL}	20		µA
All specifications at $V_{dd} = 3.3$ V			

Byte Transfer Specification

The COMPASS uses a synchronous serial signaling method to transfer data. The signaling method is compatible with SPI communications, with the COMPASS operating as a slave device on an SPI network. The $\overline{SS}$ line must be lowered (asserted) to begin a transfer and raised at the completion of the transfer. The $\overline{SS}$ line must remain de-asserted for a minimum of 2 ms between transfers. The SDO line represents the serial data out of the COMPASS, while the SDI line represents serial data into the COMPASS.

The relationships between the four lines involved in the transfer of a byte are shown in Figure 1 and Table 1.

Byte Level Protocol Specification

Common Byte Format:

Exchanges between the COMPASS and your BARGE take place with a variable number of bytes being exchanged, depending on the requested data. The first byte from the BARGE to the COMPASS is the actual command. The value returned from the COMPASS during this transfer will be `0x00`, but has no meaning. The values sent to the COMPASS as the second through n^{th} bytes of the sequence should always be `0x00`. The meanings of the values returned by the second through n^{th} byte transfers will be the results from the command byte.

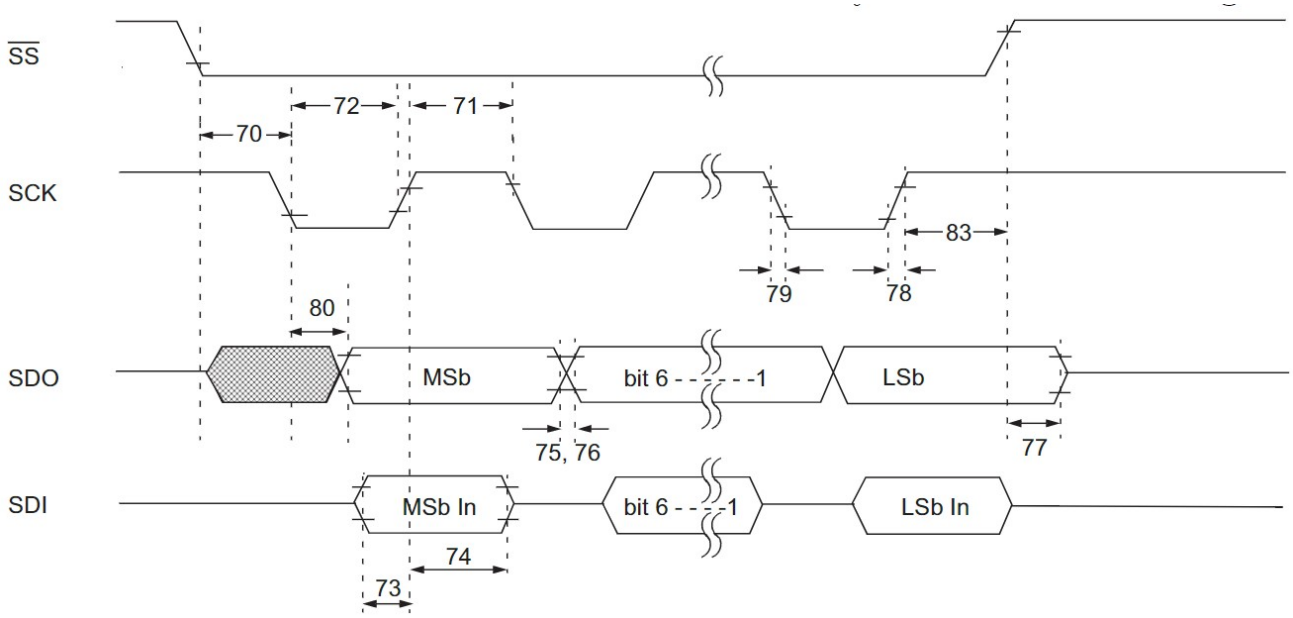

Figure 1: COMPASS SPI timing diagram.

Param No.	Symbol	Characteristic		Min	Typ	Max	Units	Conditions
70*	TssL2scH, TssL2scL	$\overline{SS}$↓ to SCK↓ or SCK↑ input		Tcy[a]	—	—	ns	
71*	TscH	SCK input high time (Slave mode)		Tcy + 20	—	—	ns	
72*	TscL	SCK input low time (Slave mode)		Tcy + 20	—	—	ns	
73*	TdiV2scH, TdiV2scL	Setup time of SDI data input to SCK edge		100	—	—	ns	
74*	TscH2diL, TscL2diL	Hold time of SDI data input to SCK edge		100	—	—	ns	
75*	TdoR	SDO data output rise time	3.0-5.5V	—	10	25	ns	
			2.0-5.5V	—	25	50	ns	
76*	TdoF	SDO data output fall time		—	10	25	ns	
77*	TssH2doZ	$\overline{SS}$↑ to SDO output high-impedance		10	—	50	ns	
78*	TscR	SCK output rise time (Master mode)	3.0-5.5V	—	10	25	ns	
			2.0-5.5V	—	25	50	ns	
79*	TscF	SCK output fall time (Master mode)		—	10	25	ns	
80*	TscH2doV, TscL2doV	SDO data output valid after SCK edge	3.0-5.5V	—	—	50	ns	
			2.0-5.5V	—	—	145	ns	
83*	TscH2ssH, TscL2ssH	$\overline{SS}$ ↑ after SCK edge		1.5Tcy + 40	—	—	ns	

* These parameters are characterized but not tested. [a]Tcy = 33μS

Table 1: COMPASS SPI timing values.

BARGE to COMPASS Bytes:

The meaningful values for the command bytes from the BARGE to the COMPASS are shown in the following table:

Command	Meaning
`REG`	Inform the COMPASS which team your BARGE is representing
`0xD2`	Return your team-assigned color and frequency information
`0xB4`	Return each team's eco-points earned via recycling
`0x78`	Return the game status
`0x69`	Return the value of each recycled item

COMPASS to BARGE Bytes:

The value returned at the same time as the command byte will always be `0x00`. This will always be followed by a value of `0xFF` as the second byte of the transfer. The values and meanings of the meaningful response bytes (3–n) returned by the COMPASS are shown in the following tables:

Command	Response Bytes	Meaning
`REG`	`ACK`	Acknowledgement of successful team registration
`0xD2`	`TEAM`	Your team-assigned color and frequency information
`0xB4`	`RCYC3`, `RCYC2`, `RCYC1`, `RCYC0`	Each team's eco-points earned via recycling
`0x78`	`STAT`	The game status
`0x69`	`VAL`	The value of each recycled item

REG: Team Registration Byte

0	0	0	$\overline{\text{TEAM}}$	0	0	0	TEAM
bit 7							bit 0

bit 0 **TEAM:** Selected Team
`0` = Register as North Team
`1` = Register as South Team

bit 5 **$\overline{\text{TEAM}}$:** Selected Team Complement
This bit should always be the complement of `TEAM`

ACK: Team Registration Acknowledgement Byte

1	0	1	0	—	—	TEAM	ACK
bit 7							bit 0

bit 0 **ACK:** Acknowledge
`0` = NACK: illegal byte format used to register
`1` = ACK: successfully registered

bit 1 **TEAM:** Registered Team
`x` = NACK, disregard
`0` = North Team
`1` = South Team

Code	0000	0001	0010	0011	0100	0101	0110	0111
Period / µs	1000	947	893	840	787	733	680	627
Code	1000	1001	1010	1011	1100	1101	1110	1111
Period / µs	573	520	467	413	360	307	253	200

Table 2: Codes for Assigned Recycling Activation Frequencies

TEAM: Assigned Team Identifiers Byte

FREQ3	FREQ2	FREQ1	FREQ0	COL2	COL1	COL0	TEAM
bit 7							bit 0

bit 7-4 **FREQ<3:0>:** Assigned check-in frequency
See Table 2 for frequency look-up table

bit 3-1 **COL<2:0>:** Assigned color
`000` = Red
`001` = Orange
`010` = Yellow
`011` = Green
`100` = Blue
`101` = Pink

bit 0 **TEAM:** Registered team
`0` = North Team
`1` = South Team

RCYC: Recycling Score Bytes

NRSC15	NRSC14	NRSC13	NRSC12	NRSC11	NRSC10	NRSC9	NRSC8
bit 31							bit 24

NRSC7	NRSC6	NRSC5	NRSC4	NRSC3	NRSC2	NRSC1	NRSC0
bit 23							bit 16

SRSC15	SRSC14	SRSC13	SRSC12	SRSC11	SRSC10	SRSC9	SRSC8
bit 15							bit 8

SRSC7	SRSC6	SRSC5	SRSC4	SRSC3	SRSC2	SRSC1	SRSC0
bit 7							bit 0

bit 31-16 **NRSC<15:0>:** North recycling score
North eco-points from recycling, represented as a 16-bit signed integer

bit 15-0 **SRSC<15:0>:** South recycling score
South eco-points from recycling, represented as a 16-bit signed integer

STAT: Game Status Byte

WR2	WR1	WR0	ER2	ER1	ER0	STATE1	STATE0
bit 7							bit 0

bit 7-5 **WR<2:0>:** West recycling accepted color
`000` = Red
`001` = Orange
`010` = Yellow
`011` = Green
`100` = Blue
`101` = Pink

bit 4-2 **ER<2:0>:** East recycling accepted color
`000` = Red
`001` = Orange
`010` = Yellow
`011` = Green
`100` = Blue
`101` = Pink

bit 1-0 **STATE<1:0>:** Game state
`00` = Waiting for Start
`01` = Cleaning Up
`10` = Game Over
`11` = *reserved*

VAL: Recycling Value Byte

VAL7	VAL6	VAL5	VAL4	VAL3	VAL2	VAL1	VAL0
bit 7							bit 0

bit 7-0 **VAL<7-0>:** Recycling value
Value in eco-points of a single unit of recycling.

Register Your Team:

To register with the field as North or South team, send a `REG` byte to the COMPASS followed by 2 bytes of `0x00`. The COMPASS will process the query and during the two `0x00` bytes of the exchange will return `0xFF`, followed by the acknowledgement of team registration as described above. Note that for each power-up of the COMPASS, this command can only be successfully executed once, and will set the registered team from that point forwards. This command must also be the first message you send (all other messages will be ignored until you send it).

Query Your Registered Team Information:

To query your assigned frequency, color, and team, send a byte of `D2` to the COMPASS followed by 2 bytes of `0x00`. The COMPASS will process the query and during the two `0x00` bytes of the exchange will return `0xFF`, followed by the `TEAM` byte as described above, containing the assigned frequency, color, and team information.

Query the Recycling Score:

To query the points accumulated by each team from recycling, send a byte of `0xB4` to the COMPASS followed by 5 bytes of `0x00`. The COMPASS will process the query and during the five `0x00` bytes of the exchange will return `0xFF`, followed by the North Team's score, then the South Team's score. Each score will be represented as a signed 16-bit big-endian value.

Query the Game Status:

To query the game status, including the current colors accepted by each recycling center, send a byte of `0x78` to the COMPASS followed by 2 bytes of `0x00`. The COMPASS will process the query and during the two `0x00` bytes of the exchange will return `0xFF` followed by the `STAT` byte containing the game status as detailed above.

Query the Value of Recycling:

To query the value of a single piece of recycling, send a byte of `0x69` to the COMPASS followed by 2 bytes of `0x00`. The COMPASS will process the query and during the two `0x00` bytes of the exchange will return `0xFF` followed by the `VAL` byte containing the recycling value as detailed above.

Power-on and Reset Behavior:

Initially, after power on or a reset, the COMPASS will return `0xFF` from any query until such time as the COMPASS is internally initialized.

Command Timing:

The interval between two successive transfers from BARGE to COMPASS should be at least 2 ms. The $\overline{SS}$ line must remain high for a minimum of 2 ms between successive transfers, and de-asserted during the entirety of a single command transfer.

Invalid Command Bytes:

If the COMPASS receives a command byte not listed in the table, it will respond to the invalid command byte by returning a series of `0xFF` bytes to the BARGE until the $\overline{SS}$ line is asserted for 2 ms.

Sample Byte Sequences:

BARGE to COMPASS	`0x78`	`0x00`	`0x00`
COMPASS to BARGE	`0x00`	`0xFF`	`0xA0`

BARGE to COMPASS	`0xB4`	`0x00`	`0x00`	`0x00`	`0x00`	`0x00`	`0x00`
COMPASS to BARGE	`0x00`	`0xFF`	`0xA0`	`0xFF`	`0xFF`	`0xFF`	`0xFF`

In these sequences, the ‘bot queries the game status (`0x78`) and the recycling score (`0xB4`) prior to registering a team. This results in the COMPASS returning a NACK (`0xA0`) for illegal registration byte format, followed by `0xFF` in response to the additional bytes of the longer transfer due to unrecognized command bytes.

BARGE to COMPASS	`0x10`	`0x00`	`0x00`
COMPASS to BARGE	`0x00`	`0xFF`	`0xA3`

BARGE to COMPASS	`0xD2`	`0x00`	`0x00`
COMPASS to BARGE	`0x00`	`0xFF`	`0xB3`

This exchange shows the result of successfully registering as South Team (`0x10`), followed by a query for team-assigned information (`0xD2`) indicating that the assigned frequency has period of 413 µs, the assigned color is orange, and that registration is as South Team.

BARGE to COMPASS	`0xB4`	`0x00`	`0x00`	`0x00`	`0x00`	`0x00`
COMPASS to BARGE	`0x00`	`0xFF`	`0x00`	`0x72`	`0x00`	`0xAB`

The next query (`0xB4`) demonstrates requesting the recycling score. The returned result indicates a score of North 114, South 171.

Physical Specifications

Dimensions:

The COMPASS dimensions are 2” $\times$ 3” $\times$ 1”.

Revision History

Rev 0: First draft, out for review. (1/31/19)

Rev 1: Published with project description. (2/6/19)