

**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 field and beat the buzzer in an exciting combination of two classic Earth sports.

**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:**

After reviewing your stellar bids for the opening ceremony of this year's Intragalactic Olympic Games, the Intragalactic Olympic Committee has decided to extend invitations to your home planets to, like, compete in the games or something. The IOC has requested that each of your worlds sends an Autonomously Traversing High/Low Ejection Targeting Entity (ATHLETE) to compete in the games.

To commemorate the Games of the 4095<sup>th</sup> Olympiad, the IOC has decided to bring back a historical favorite from the early days of Earth; but since the host planet has no seasons, the committee combined their favorite winter and summer sports, hockey and basketball. The result is a Superior Planetary Ambassador's Competitive Evaluation of Justifiably Astronomical Magnitude (SPACE JAM). This game will be played on a field representing the reaches of the Galaxy: black for the void of space, blue for the actinic glare of newly formed stars, red for the warm glow of fading red giants, and purple for the satisfying taste of Purple Flurp™. Relax with the satisfying taste of Purple Flurp™, proud sponsors of the Games of the 4095<sup>th</sup> Olympiad!

We are excited to welcome the ATHLETES from many esteemed and varied cultures from across the galaxy. Out of respect for the competitors from all delegations, we ask that when you're welcomed to the 'JAM, you resist the impulse to come on and slam.

**The Task:**

Your ATHLETES 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.

*It's gut-check time!*

*Daffy Duck*

**Specifications****The Field:**

- The field is an approximately 8'×8' area with exterior walls 3.5" tall. A top view is shown in Figure 1.
- The playing surface of the field will have a linear 2D color gradient, with a red gradient in one direction, and a superimposed blue gradient at 90 degrees.
- The resulting field will have a pure blue corner at the top left, pure red at bottom right, purple at bottom left, and black at top right, per Figure 1.
- This color gradient will be covered by a 1/8" thick PETG protective sheet.
- The goals are located on two opposing edges of the field ("end boards").
- Each goal has a modulated IR beacon mounted on the backboard, with the emitters located 13.25" above the surface of the field.

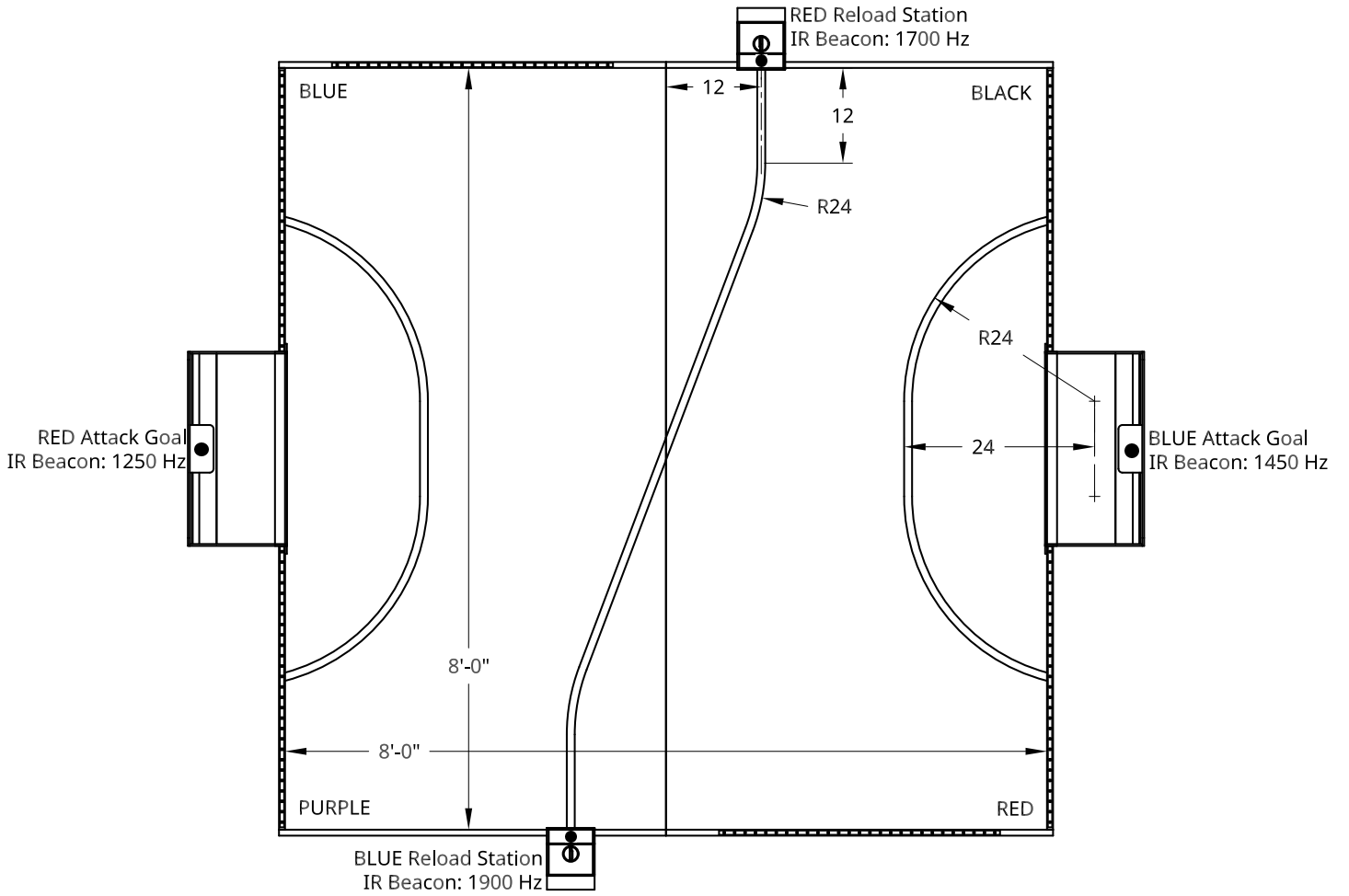


Figure 1: The field.

- The RED attack goal beacon emits IR modulated with a period of 800  $\mu$ s.
- The BLUE attack goal beacon emits IR modulated with a period of 700  $\mu$ s.
- Reloading stations are located on the remaining two edges of the field (“side boards”), with the center of the reload station 12” away from the midline.
- Each reload station has a modulated IR beacon mounted on top of it, with the emitters located 13.25” above the surface of the field.
- The beacon on the RED reload station emits IR modulated with a period of 600  $\mu$ s.
- The beacon on the BLUE reload station emits IR modulated with a period of 500  $\mu$ s.
- The reload stations 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 region in front of the goal (“the crease”) will be marked around each goal by a 1” black tape line, as shown in Figure 1.

### The ATHLETE:

- Your ATHLETE 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 ATHLETE must have a mechanism to designate the ATHLETE as RED or BLUE.
- Each ATHLETE must include a means to clearly indicate to the audience its RED/BLUE status.
- ATHLETES must be autonomous and untethered.
- The only parts of the ATHLETE that may ever touch the playing field surface are wheels, ball transfers, or slippery supports used to balance the ATHLETE.
- There must be a bumper surrounding the perimeter of your ATHLETE extending for at least 2” vertically, and must 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.
- Your ATHLETE 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.
- Each ATHLETE may start a round loaded with 1 BALL<sup>1</sup>, if desired by your team.
- Your ATHLETE may launch BALLs either horizontally at floor level or with a substantially above-horizontal trajectory. In either case, the BALL may land no more than 9’ from the ATHLETE and reach a peak height of no more than 8’ above the floor of the playing field.
- Each ATHLETE must carry an easily accessible switch which shall cut power to the ATHLETE in case of a software or hardware malfunction.
- Each ATHLETE must be constructed as part of ME218b. It may not be based on a commercial or otherwise preexisting platform.
- Any exterior corners on the ATHLETE must have a radius of at least 1/2”.
- To comply with IOC regulations, you are limited to an expenditure of **\$200.00/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 ATHLETE must provide a clearly visible indicator when it thinks that the game is in progress. This indicator should be activated when the ATHLETE determines that a game has started and be deactivated

<sup>1</sup>Not an acronym; literally a small, spherical object, often used in games and beachfront<sup>2</sup> activities.

<sup>2</sup>On planets with large bodies of water, beaches occur where there is a large quantity of sand<sup>3</sup> adjacent to a large body of water.

<sup>3</sup>For those from planets with no sand: it is coarse and rough and irritating and it gets everywhere.

when the game status indicates the end of the game.

- Only the supplied motors may be used to drive anything that transfers force to the ground.

### The Goals:

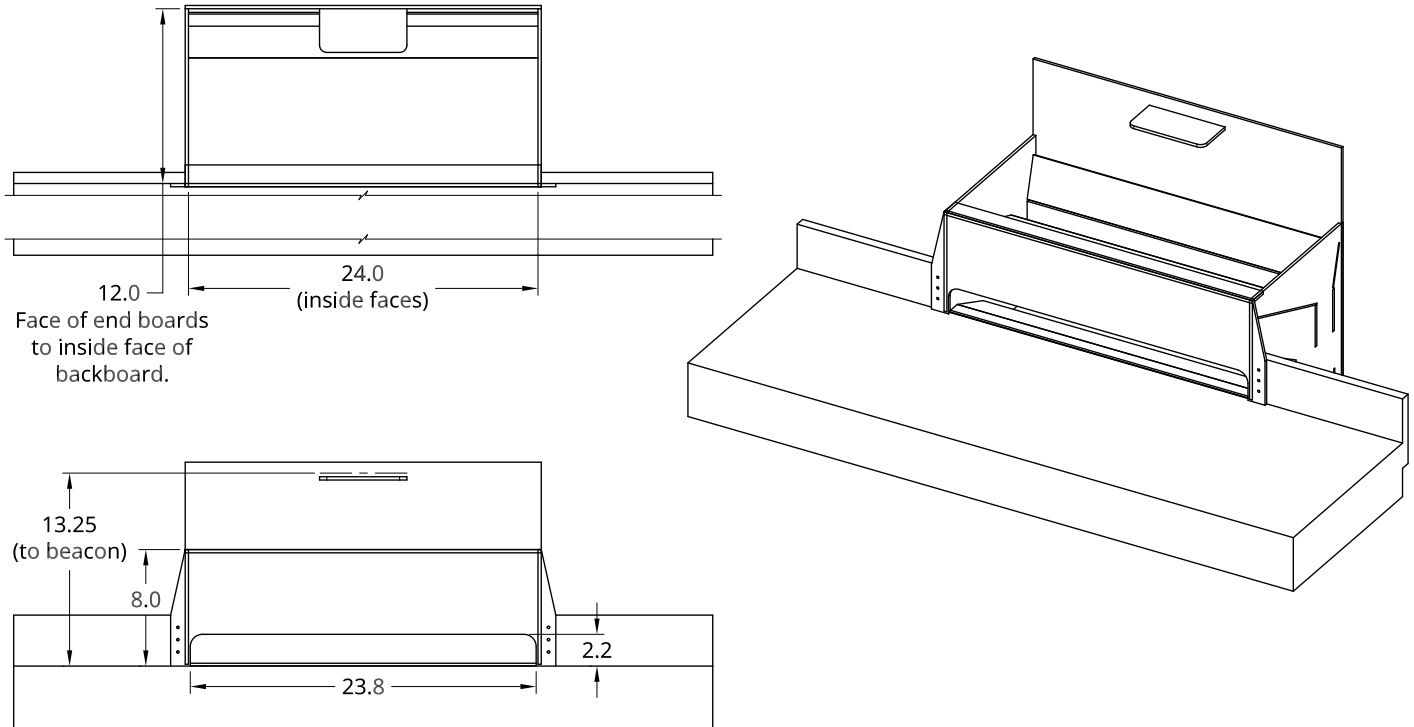


Figure 2: The goal.

- Each goal will have two openings for scoring BALLS. Dimensioned and isometric views of a goal are presented in Figure 2.
- The first of these openings will be at floor level, and measures 2' in width and 2.2" in height.
- The second opening opens upwards, is 8" above the playing surface, and has an area of 2' in width and 1' in depth.
- This second opening has a backboard extending to 14" above the playing surface. The IR beacon is attached to this backboard.
- The goals will detect a goal when a BALL is shot through either opening and remains in the goal.

### The Reload Stations:

- Figure 3 shows dimensioned and isometric views of a reload station.
- Each ATHLETE has a dedicated reload station located on one of the side boards.
- In order to request that the reload station dispense a BALL, the ATHLETE must measure a pulsed IR emission from the reload station, and respond to the reload station with an IR signal modulated at twice ( $\pm 1\%$ ) the frequency of the pulsed emission.
- The IR signal emitted from the reload stations will be modulated in the range from 500–1000 Hz.
- The IR emitter on the reload station will be located 8" above the surface of the field and centered on the width of the reload station.

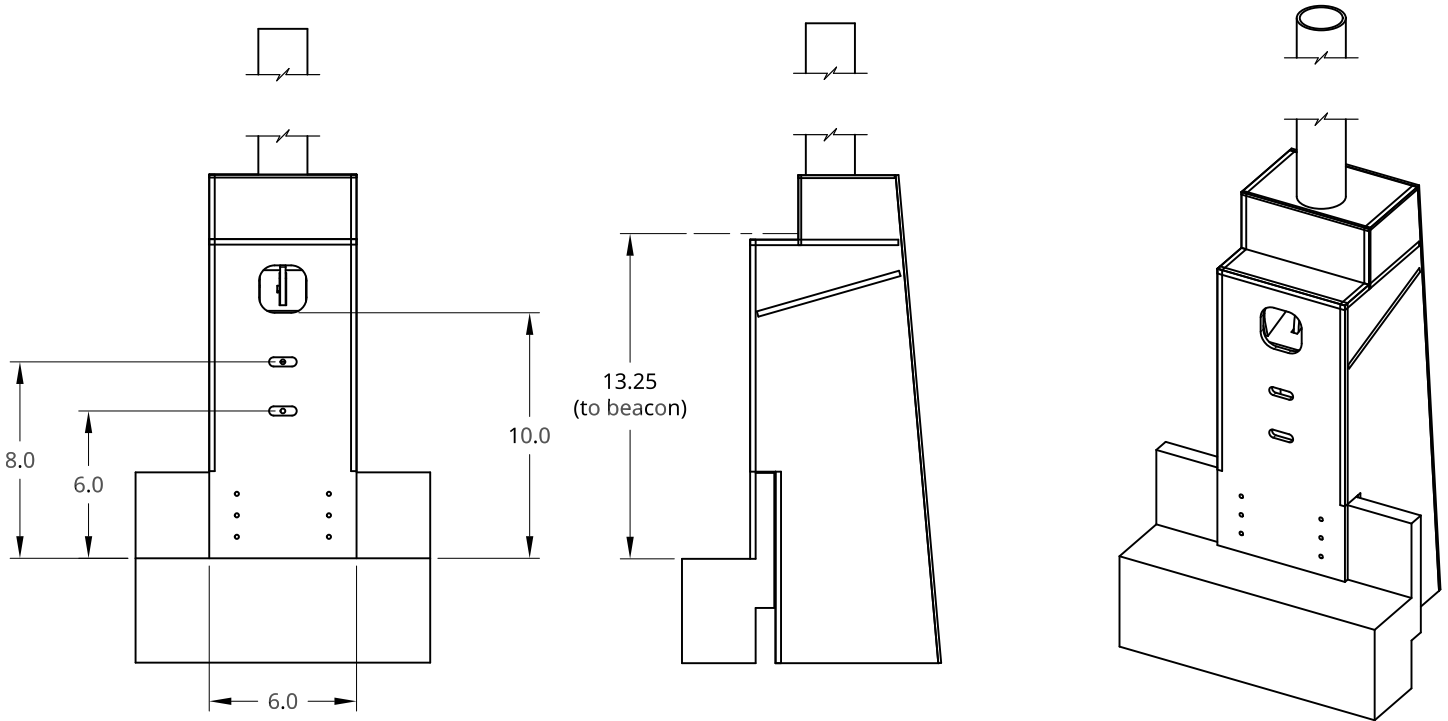


Figure 3: The reload station.

- The IR receiver on the reload station will be located 6" above the surface of the field and centered on the width of the reload station.
- BALLs will be dispensed from a ramp at a height of 10" above the surface of the field and centered on the width of the reload station.

**The REF:**

- The Radio Equipped Facilitator (REF) will provide information to the ATHLETE about the status of the game.
- The REF will communicate with your ATHLETE over a 4-wire SPI bus.
- The REF will be recognized by and communicate wirelessly with the field, so it should be mounted where it will have good radio reception.
- A complete description of the REF, 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 ATHLETES as they attempt to score goals using BALLs.
- Each game will last for 2 minutes, 18 seconds.
- At the end of 2:18, the ATHLETE with the most goals is the winner.
- The RED ATHLETE will start the game in the red corner, with the ATHLETE contacting both the end and side boards.
- The BLUE ATHLETE will start the game in the blue corner, with the ATHLETE contacting both the end and side boards.
- The game will begin when a query to the REF indicates that the game state has changed from "Waiting for Start" to "Face-off".

- During the Face-off period, the ATHLETES will race to their respective reload stations. The first ATHLETE to successfully reload will gain possession, and the game state will change from “Face-off” to “Playing”. If neither ATHLETE successfully reloads within 30 s, possession will be randomly assigned to one ATHLETE.
- The shot clock starts any time an ATHLETE gains possession, starting at a value between 10–25 s and counting down. Possession changes to the other team any time the shot clock expires.
- The game will proceed in a series of alternating possessions, with each possession ending when the attacking team scores, or when the shot clock expires.
- Each team’s attacking goal is only active when it has possession. (e.g. the RED ATHLETE may only score on the RED attack goal when RED has possession)<sup>4</sup>. This implies that is impossible to score more than once per possession, since possession changes as soon as the first score is made.
- If the score is tied at the end of the 2:18 regulation time, the game state will change to “Tie-break”, and the first ATHLETE to successfully reload will win the game. If neither ATHLETE successfully checks in within 20 s, a random ATHLETE will be selected as the winner.
- When a winner is decided, whether in regulation or in overtime, the game state will change to “Game Over”. At this point your ATHLETE must cease attempting to score.
- After accepting a request to deliver a BALL, each reload station ignores further requests for a period of (shot clock interval/2) seconds<sup>5</sup>.

### Rules:

- No solderless breadboards are permitted in the final project.
- Contact is permitted, but intentional interference with the operation of another ATHLETE is prohibited.
- Each ATHLETE must start and remain in one piece during the round. Any locomotion of the ATHLETE should cause all parts of the ATHLETE to move.
- Your ATHLETE 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.
- ATHLETES may only reload from their assigned reload station.
- Intentional jamming of your opponent’s senses or violation of the communications protocol is prohibited.
- Any IR emission from your ATHLETE **MUST** be confined to the volume within 7” above the surface of the field.
- Your robot may not present obstructions to the IR beacon spanning more than 7.5 degrees of arc in total within the volume between 12” and 14” above the playing field. This limit may be exceeded for brief periods not exceeding 1 s, and not more than 5% of total game time.
- 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 ATHLETE should be safe, both to the user and the spectators. The teaching staff reserves the right to disqualify any ATHLETE considered unsafe. This also applies during testing, so keep the ATHLETE velocity and shooting velocity low enough so as not to cause problems.
- ATHLETES must be stable in the presence of a 30 mph wind.

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<sup>4</sup>The BLUE robot may also score on the RED attack goal when RED has possession. This will result in a point for RED, and much hilarity at BLUE’s expense.

<sup>5</sup>That is, if the shot clock initializes to 14 s, then each reload station delivers at most one BALL every 7 s. This rate is independent of which ATHLETE has possession.

- 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 ATHLETE 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 ATHLETE at all times.
- Any early celebrations will be penalized.
- ATHLETES may alter the space-time continuum only during the public presentations.

## Checkpoints

### Design Review:

During the day on **February 13** 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.

*But I'm a baseball player now!*

*Michael Jordan*

### First Checkpoint:

On **2/15/18**, you will turn in 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. An Altium schematic in a word document describing your core functionality should be uploaded to Gradescope. Only one team member needs to submit your checkpoint documentation.

*Well, I may not be very tall, but... I'm slow.*

*Stan Podalak*

### Second Checkpoint:

On **2/20/18**, you must demonstrate your untethered, motorized platform moving under autonomous software control. Your platform must be able to drive across the field and back under software control.

*Let's do some drills*

*Michael Jordan*

### Third Checkpoint:

On **2/23/18**, you must demonstrate the integration of the REF with your mobile platform and the ability of your ATHLETE to communicate with the REF to exercise all of the REF's capabilities. Evidence of achieving this functionality will be demonstrated by your ATHLETE initiating motion based on the game status information from the REF changing from "waiting" to "faceoff".

*Too bad you can't practice getting taller, boys.*

*Daffy Duck*

### Fourth Checkpoint:

On **2/27/18**, you must demonstrate your robot's ability to

1. Navigate to the reload station upon the game status changing from "waiting" to "faceoff".
2. Communicate with the reload station to successfully reload.

*Don't lose that confidence, okay, paws and wings in here, all right!*

*Bill Murray*

### **Project Preview:**

At the Project Preview on **3/3/18**, each ATHLETE must demonstrate, in an integrated form,

1. The ability to move around the field under software control.
2. The ability to communicate with the REF.
3. The ability to reload.
4. The ability to orient and shoot at the goal.

This will be tested by communicating a “Face-off” status followed by the ATHLETE proceeding to the reload station, reloading, and shooting at a goal.

*Lemony fresh!*

*Taz*

### **Grading Session:**

During the Grading Session on **3/5/18** each ATHLETE will be required to demonstrate a complete game. The evaluation will take place with only a single ATHLETE on the field, competing and scoring against a static dummy. During this game, when possession transfers to the opposing team, your ATHLETE must demonstrate some non-offensive action. Evaluation for grading purposes will only occur during these sessions. If your ATHLETE fails at its first attempt to demonstrate its ability, it must then demonstrate the ability two times in a succession at its next attempt. These increases continue after repeated failed attempts to a maximum of 4 required successive demonstrations.

*Thanks guys, you got a lot of... a lot of... well, whatever it is, you got a lot of it.*

*Michael Jordan*

### **Public Presentation:**

This will take place on **3/7/18** starting at **7:00 pm** in the Atrium of Building 550.

*Please! What kind of Mickey Mouse organization would name their team The Ducks?*

*Bugs Bunny*

### **Report:**

Draft due on **3/12/18** by 4:00 pm. The final version with revisions is due by 5:00 pm on **3/16/18**.

*It wasn't a dream, it really happened!*

*Charles Barkley*

## **Evaluation**

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### **Performance Testing Procedures:**

One or more team members will operate the ATHLETE during the performance evaluation. A competition among the class' ATHLETES 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, 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. The actual website must be submitted as a **single Zip file** (7-zip is installed on all the workstations in the lab). In addition, if your website is hosted, you must **include a text file with the URL to your site**. 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 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 (also in the form of a single zip file plus URL) by 5:00 pm on 3/16/18. The front page of your project description must be in a file called `index.html` at the root folder of the web site. Test your zip-file by unzipping it into an empty folder. Once un-zipped, you should be able to view the entire site starting from the `index.html` file. 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 ATHLETE realistically be built for \$200? 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 3/13/18.
- **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

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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.

## Resources

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### Websites:

[SparkFun](#)

[Mouser](#)

[Adafruit](#)

[McMaster-Carr](#)

[Seeed Studio](#)

[Newark](#)

[Hackaday](#)

[HobbyKing](#)

[Jameco](#)

[Ponoko](#)

[DigiKey](#)

[ServoCity](#)

### 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.

**Purpose:**

The primary purpose of the Radio Equipped Facilitator (REF) is to act as a gateway to the field infrastructure to allow your ATHLETE to request information about the state of the game.

**Interface Connection**

**Connector:**

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

**Pinout:**

Pin	Name/Function
1	+3.3V (@ 100mA) / Power to the REF ( $V_{dd}$ )
2	SDI / Serial Data Into the REF
3	SDO / Serial Data Out of the REF
4	SCK / Serial Clock
5	SS / active low select line for the REF with on-board pull-up to +3.3V
6	GND / Ground reference for the REF



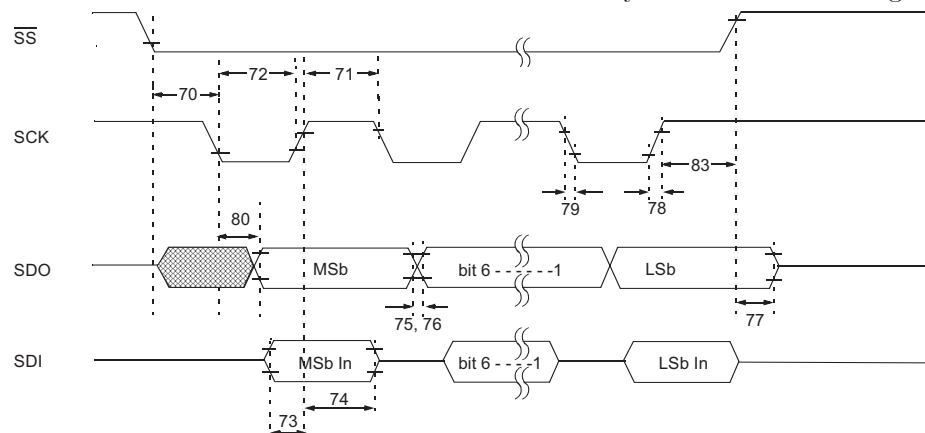
**Electrical Specifications**

Parameter	Min.	Max	Units
$V_{iH}$	$V_{dd} * 0.65$		V
$V_{oH}$	$V_{dd} - 0.4$		V
$V_{iL}$		$V_{dd} * 0.35$	V
$V_{oL}$		0.4	V
$I_{iH}, I_{iL}$		$\pm 1$	$\mu A$
$I_{oH}$	-20		$\mu A$
$I_{oL}$	20		$\mu A$
All Specifications at $V_{dd} = 3.3V$			

**Byte Transfer Specification**

The Radio Equipped Facilitator uses a synchronous serial signaling method to transfer data into and out of the REF. The signaling method is compatible with SPI communications, with the REF operating as a slave device on an SPI network. The  $\overline{SS}$  line must be lowered (asserted) to begin a 4-byte (40 bit) transfer and raised at the completion of the 4-byte transfer. The  $\overline{SS}$  line must remain de-asserted for a minimum of 2ms between transfers. The SDO line represents the serial data out of the REF, while the SDI line represents serial data into the REF.

The relationships between the four lines involved in the transfer of a byte are shown in the figure & table below:



## Radio Equipped Facilitator Documentation 2

Param No.	Symbol	Characteristic	Min	Typ	Max	Units	Conditions
70*	TssL2sCH, TssL2sCL	$\overline{SS} \downarrow$ to SCK $\downarrow$ or SCK $\uparrow$ input	T <sub>CY</sub> <sup>a</sup>	—	—	ns	
71*	Tsch	SCK input high time (Slave mode)	T <sub>CY</sub> + 20	—	—	ns	
72*	TscL	SCK input low time (Slave mode)	T <sub>CY</sub> + 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	$\overline{SS} \uparrow$ 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	$\overline{SS} \uparrow$ after SCK edge	1.5T <sub>CY</sub> + 40	—	—	ns	

\* These parameters are characterized but not tested. <sup>a</sup>T<sub>CY</sub> = 33μS

## Byte Level Protocol Specification

### Common Byte Format:

Exchanges between the Radio Equipped Facilitator (REF) and your ATHLETE take place with four successive bytes being exchanged. The first byte from the ATHLETE to the REF is the actual command. The value returned from the REF during this transfer will be 0x00, but has no meaning. The values sent to the REF as the second through fourth bytes of the sequence should always be 0x00. The meanings of the values returned by the second through fourth byte transfers will be the results from the command byte.

### ATHLETE to Radio Equipped Facilitator Bytes:

The meaningful values for the command bytes from the ATHLETE to the Radio Equipped Facilitator are shown in the following table:

Command	Meaning
0x3F	Request the status of the game.
0xC3	Request the current score in the game.

### Radio Equipped Facilitator to ATHLETE Bytes:

The values and meanings of the response bytes returned by the Radio Equipped Facilitator are shown in the following table:

Command	Response Bytes	Description of meaning
0x3F	0xFF, <b>SC</b> , <b>SS</b>	<b>SC</b> = shot clock time remaining: 0.1sec/count; <b>SS</b> = game status: Bits 0-2: 000 = Waiting for Start; 001 = Face-off, 010 = Playing, 011 = Tie-break; 1xx = Game Over; Bits 4-5: 00 = No one in possession, 01 = RED in possession, 10 = BLUE in possession.
0xC3	0xFF, <b>RR</b> , <b>BB</b>	Score in the match: <b>RR</b> = score for RED team, <b>BB</b> = Score for BLUE team

**Query the Status of the Game:**

To query the game status, send a byte of 0x3F to the REF followed by 3 bytes of 0x00. The REF will process the query and during the three 0x00 bytes of the exchange will return 0xFF, followed by the two status/info bytes as described above.

**Query the Score:**

To query the game score, send a byte of 0xC3 to the REF followed by 3 bytes of 0x00. The REF will process the query and during the three 0x00 bytes of the exchange will return 0xFF, followed by the RED team's score followed by the BLUE team's score.

**Power on and reset behavior:**

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

**Command Timing:**

The interval between two successive transfers from ATHLETE to Radio Equipped Facilitator should be at least 2ms. The  $\overline{SS}$  line must remain high for a minimum of 2ms between successive transfers.

**Invalid Command Bytes:**

If the Radio Equipped Facilitator receives a command byte not listed in the table, it will respond to the invalid command byte by queuing a series of 0xFF bytes to be returned to the ATHLETE.

**Sample Byte Sequences:**

<b>ATHLETE to REF</b>	0x3F	0x00	0x00	0x00
<b>REF to ATHLETE</b>	0x00	0xFF	0x00	0x00

In this sequence, the ATHLETE queries the game state (0x3F), which will return 0xFF, then 0x00 followed by 0x00 if the game has not started yet and therefore no one has possession.

<b>ATHLETE to REF</b>	0x3F	0x00	0x00	0x00
<b>REF to ATHLETE</b>	0x00	0xFF	0x65	0x12

The next query (0x3F) shows the result from a status request during active play when RED is in possession and 10.1 seconds remain on the shot clock.

<b>ATHLETE to REF</b>	0xC3	0x00	0x00	0x00
<b>REF to ATHLETE</b>	0x00	0xFF	0x0A	0x0B

The next query (0xC3) demonstrates requesting the score. The returned result indicates a score of RED = 10, BLUE = 11.

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## Physical Specifications

**Dimensions:**

The Radio Equipped Facilitator dimensions are 2" x 3" x 1".

**Revision History:**

Rev 0: First draft, out for review.

Rev 1: Included comments on wording and layout changes