ME 218b Winter 2020: Capitalism: The Final Frontier

Our three week mission: to exploit strange new worlds, to boldly mine where no corporation has mined before.
Project Preview on February 29 from 1-5 pm.
Grading Period begins February 29, and runs through 11:59 pm on March 3.
Project Presentation on March 4 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 Peterson Pediment and successfully mine resources.

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:

The colony has established a foothold on Mars, and surveys by the research geologists have indicated that there may be rich veins of rare element ores—including element 218, Obtainium. You're a young engineer working for Carryer-Kenny Holdings (CKH)—a large multinational conglomerate with interests in nearly every industry—and want to make your name (and your fortune) on Mars. The shareholders have paid for your trip to Mars, and gave you a pair of Mineral Identification, Nucleation, and Extraction Rigs (MINERs), so all you have to do is find some ore and make your fortune... or at least enough to pay for your ticket home. Unfortunately they forgot to give you a way to move the MINERs around, so you'll have to build a TRACTOR for Commercializing The Obtainable Resources (TRACTOR) yourself to get the MINERs to where they're needed. Your intel suggests the most concentrated deposits of Obtainium can be found in Peterson Pediment[1], and so you've hauled your MINERs and TRACTOR out to the desolation, far from the existing human habitation.

Be careful though; while a permitting system is in place, Mars is a long way from the law and other corporations—including your chief competitor, Gumerlock Heavy Industries (GHI)—are out to beat you to the rocks.

The Task:

Your TRACTORs 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.

> *You haul sixteen tons, what do you get?*
> *Another day older and deeper in debt*
> *Saint Peter don't call me 'cause I can't go*
> *I owe my soul to the company store*

> *Tennessee Ford, Sixteen Tons*

Specifications

The Peterson Pediment:

☐ The Peterson Pediment is an approximately 2.5×2.5 m area with exterior walls 9 cm tall. A top view is shown in Figure 1.

☐ The Peterson Pediment will be covered by a 3 mm thick PETG protective sheet.

☐ The Peterson Pediment is divided into 16 roughly equal-sized regions.

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[1]*pediment*, n. a very gently sloping bedrock surface with a slope between 0.5° and 7°. *Encyclopædia Britannica*.
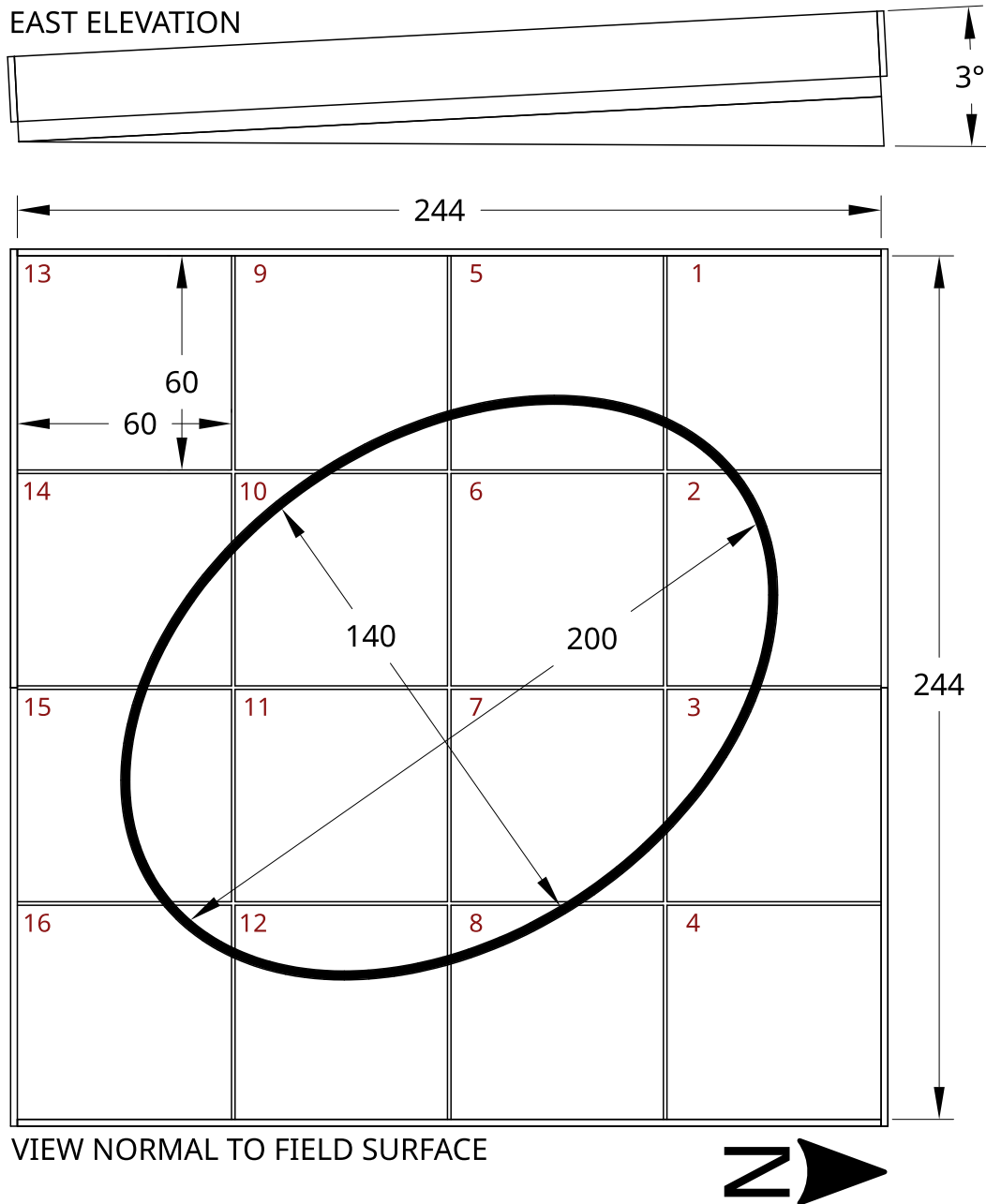
Figure 1: Overhead and side views of the Peterson Pediment. The field is divided into 16 approximately square regions, each of which has a different color, numbered sequentially from the northwest corner. The regions are divided by at least 2 cm of white, along with inlaid RGB LED strips along the division lines. The regions and the gaps between are covered by a layer of clear PETG sheet. A tape loop is provided, and will be on top of the PETG surface of the Peterson Pediment. The tape is 2.5 cm in width, and with a centerline described by an ellipse aligned with the center of the field, with major axis of 200 cm and minor axis of 140 cm. The angle between the major axis and north is 35°. The Peterson Pediment is tilted by the addition of wedges under the substructure, resulting in a north-to-south tilt of approximately 3°. All linear dimensions in centimeters.

Beacon	Frequency	Period
CKH MINER.One	3333 Hz	300 µs
CKH MINER.Two	2000 Hz	500 µs
GHI MINER.One	1429 Hz	700 µs
GHI MINER.Two	909 Hz	1100 µs

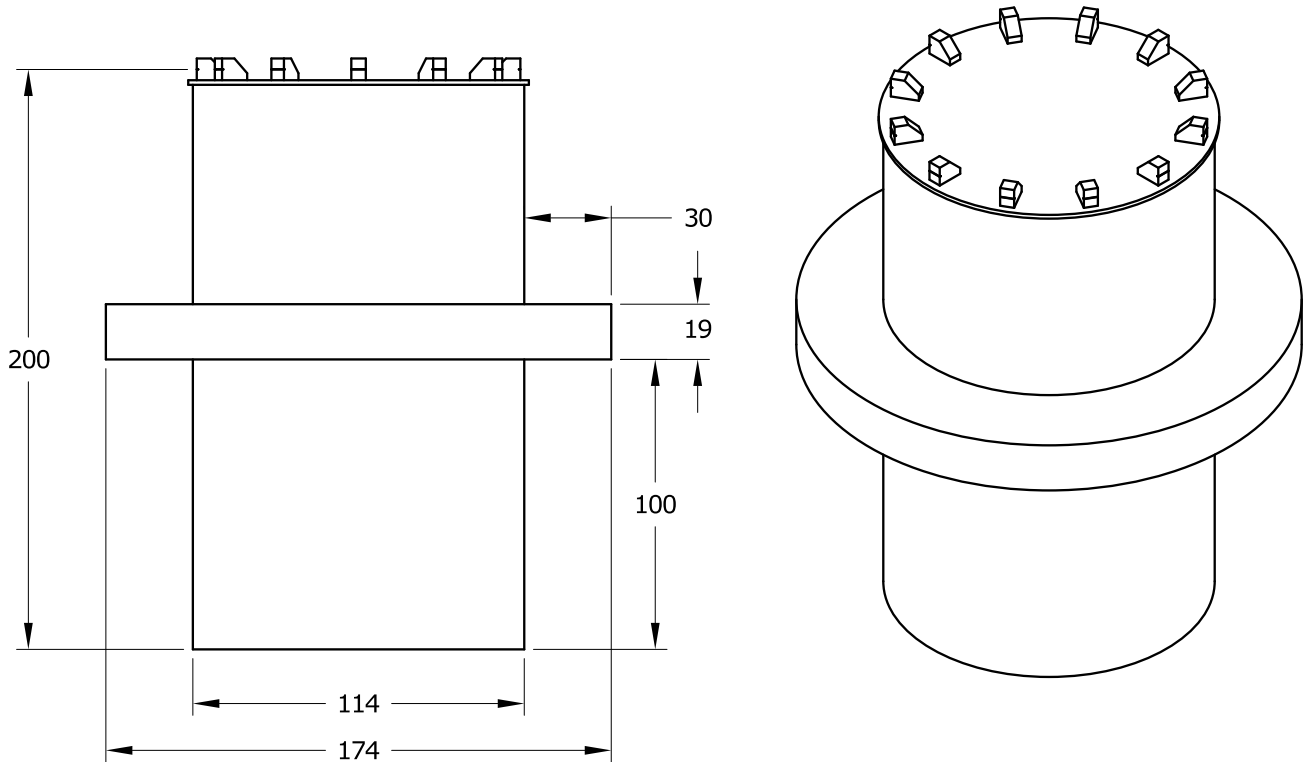Table 1: Beacon Modulation Frequencies

Figure 2: The MINERs. All dimensions in millimeters.

☐ Each rectangle will have a unique color under the PETG sheet. Colors will be separated by a white border of approximately 3 cm.

☐ There will be LED strips inlaid into the field at the borders of the rectangular regions. Behavior of these LEDs may change as they are primarily intended for display to spectators; while you should be robust to the LEDs turning on and off, do not depend on them for navigation. The LED colors will always be selected such that they are distinct from the region colors.

☐ The Peterson Pediment will be tilted by approximately 3° such that the north edge is approximately 15 cm higher than the south edge.

☐ A loop of 2.5 cm black tape line will traverse much of the Peterson Pediment, 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 TRACTOR:
☐ Your TRACTOR 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 TRACTOR must have a mechanism to designate the TRACTOR as owned by CKH (red) or GHI (blue).

☐ Each TRACTOR must include a means to clearly indicate to the audience its company status.

☐ TRACTORs must be autonomous and untethered.

☐ The only parts of the TRACTOR that may ever touch the playing surface are wheels, ball casters, or slippery supports used to balance the TRACTOR.

☐ 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 TRACTOR extending for at least 5 cm vertically, and must fully cover the region between 5 cm and 8 cm (± 5 mm) 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 5 cm and 8 cm from the floor.

☐ Your TRACTOR must be fully contained within a 30 cm cube at the beginning of the mining operations.

☐ Each TRACTOR must carry an easily accessible switch which shall cut power to the TRACTOR in case of a software or hardware malfunction.

☐ Each TRACTOR must be constructed as part of ME218b. It may not be based on a commercial or otherwise preexisting platform.

☐ Any exterior corners on the TRACTOR must have a radius of at least 12 mm.

☐ The accounting department has limited you 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 TRACTOR must provide a clearly visible indicator when it thinks that mining operations are in progress. This indicator should be activated when the TRACTOR determines that mining operations have started and be deactivated when the mining operations status indicates the end of the mining operations.

The MINERs (provided by the SPDL Staff):

☐ Figure 2 shows dimensioned and isometric views of a MINER.

☐ MINERs are capable of sliding on the floor and do not need to be lifted to be moved.

☐ MINERs will have a ferrous material wrapped around the rim of the flange.

☐ Each MINER will carry an IR beacon which will emit IR in a full circle at a level 20 cm above the surface of the Peterson Pediment.

☐ Each MINER will modulate the IR beacon at a unique frequency, as defined in Table 1.

☐ MINERs will detect what region of the Peterson Pediment they are in and will relay this information to your TRACTORs. See the attached protocol definition for details of this information.

The SPUD (provided by the SPDL Staff):

☐ The Synchronized Permitting and Usage Designator (SPUD) will provide information to the TRACTOR about the status of the mining operations.

☐ The SPUD will communicate with your TRACTOR over a 4-wire SPI bus.

☐ The SPUD will be recognized by and communicate wirelessly with the Peterson Pediment.

☐ A complete description of the SPUD, from both an electrical and protocol standpoint, is included in an appendix that accompanies this project description.

The Mining Operations:
- ☐ The mining operations are a head-to-head contest between two competing corporate TRACTORs as they attempt to control regions of the Peterson Pediment by moving MINERs.
- ☐ Each period of mining operations will last for 2 minutes, 18 seconds.
- ☐ At the end of 2:18, the TRACTOR which collected the most Obtainium is the winner.
- ☐ At the beginning of the mining operations, the CKH TRACTOR will be placed somewhere on the North half of the Peterson Pediment by a member of the teaching staff.
- ☐ At the beginning of the mining operations, the GHI TRACTOR will be placed somewhere on the South half of the Peterson Pediment by a member of the teaching staff.
- ☐ The mining operations will begin when a query to the SPUD indicates that the operations state has changed from "Waiting for Permits" to "Permits Issued".
- ☐ During the course of the mining operations, the Peterson Pediment will randomly designate four color regions on the Peterson Pediment as actively permitted regions. These active regions will change over the course of the game.
- ☐ One of these regions will be permitted for the exclusive use of CKH, and only CKH may mine Obtainium in that region.
- ☐ One of these regions will be permitted for the exclusive use of GHI, and only GHI may mine Obtainium in that region.
- ☐ The remaining two regions will be available for either corporation to mine.
- ☐ TRACTORs can accumulate resources by moving a MINER into either of the two neutral regions, or into the mining region that is exclusively assigned to their corporation.
- ☐ Resources may only be mined in active regions containing exactly one MINER. Any active region with two or more MINERs located in it will accumulate no resources for either TRACTOR.
- ☐ TRACTORs are allowed to to interact with any MINER.
- ☐ If both corporations have equal amounts of Obtainium at the end of the 2:18 regulation time, there will be a sudden-death period of 21.8 s, with new active mining regions. If the resources collected are still equal when sudden death ends, the game will be decided by an extremely dramatic coin flip.
- ☐ When the clock expires, the operations state will change to "Permits Expired". At this point your TRACTOR must cease attempting to collect resources.

Rules:
- ☐ No solderless breadboards are permitted in the final project.
- ☐ A TRACTOR that makes contact with another TRACTOR must move away from the contact. Incidental contact will not be penalized, but persistent contact of more than three seconds with another TRACTOR will result in an assessed penalty of resources.
- ☐ Intentional interference with the operation of another TRACTOR is prohibited.
- ☐ Intentionally tipping a MINER is prohibited[2].
- ☐ Any tipped MINER will be reset, upright, onto a non-active region by a member of the teaching staff.
- ☐ Each TRACTOR must start and remain in once piece during the round. Any locomotion of the TRACTOR should cause all parts of the TRACTOR to move.
- ☐ Your TRACTOR may not **IN ANY WAY** alter the condition (e.g. mar the walls or the floor) of the playing

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[2]As a guideline for what might be considered "intentional": if your TRACTOR is operating alone on the field with only one MINER, it should not under normal operation tip the MINER. Make sure that you have designed the interaction to be robust to normal variations in contact conditions.

field or the MINERs. 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 or other supports 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 TRACTOR **MUST** be confined to the volume within 15 cm of the surface of the Peterson Pediment.

☐ 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 TRACTOR should be safe, both to the user and the spectators. The teaching staff reserves the right to disqualify any TRACTOR considered unsafe. This also applies during testing, so keep the TRACTOR velocity low enough so as not to cause problems.

☐ You must make a stand to support your TRACTOR on the table for testing. The purpose of the stand is to prevent an errant TRACTOR from running off of the table during testing.

☐ TRACTORs must be stable in the presence of a 15 m/s wind.

☐ No part of the machine may become ballistic. Also, MINERs may not become ballistic.

☐ 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 TRACTOR 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 TRACTOR at all times.

☐ Any early celebrations will be penalized.

☐ Your TRACTOR is not permitted to steal talent from any other TRACTORs.

☐ TRACTORs may alter the space-time continuum only during the public presentations.

Checkpoints

Design Review:

During the day on **February 11** 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.

> *The man who moves a mountain begins by carrying away small stones.*
>
> *Confucius*

First Checkpoint:

On **2/13/20**, 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.

The production of too many useful things results in too many useless people.

Karl Marx

Second Checkpoint:

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

The meek shall inherit the earth, but not its mineral rights.

J. Paul Getty

Third Checkpoint:

On **2/21/20**, you must demonstrate the integration of the SPUD with your mobile platform and the ability of your TRACTOR to communicate with the SPUD to exercise all of the SPUD's capabilities. Evidence of achieving this functionality will be demonstrated by your TRACTOR initiating motion based on the operation status information from the SPUD changing from "Waiting for Permits" to "Permits Issued".

I don't care half so much about making money as I do about making my point, and coming out ahead.

Cornelius Vanderbilt

Fourth Checkpoint:

On **2/25/20**, you must demonstrate your robot's ability to

1. Start navigating upon the game status changing from "Waiting for Permits" to "Permits Issued".
2. Navigate to a MINER.
3. Move the MINER to a different region.

Well, they dug for their coal till the land was forsaken
Then they wrote it all down as the progress of man

John Prine, Paradise

Project Preview:

At the Project Preview on **2/29/20**, each TRACTOR must demonstrate, in an integrated form,

1. The ability to move around the Peterson Pediment under software control.
2. The ability to communicate with the SPUD.
3. The ability to move a MINER.
4. The ability to collect Obtainium by successfully positioning a MINER in an active region.
5. The ability to back away on contact with another TRACTOR.

This will be tested by communicating a "Permits Issued" status followed by the TRACTOR proceeding to navigate around the field, moving a MINER, and collecting resources by positioning it correctly. At some point during this sequence, your TRACTOR will encounter a standard SPDL-prepared opponent, and must demonstrate the ability to back away in the case of contact between your TRACTOR and the opponent.

Earth provides enough to satisfy every man's needs, but not every man's greed.

Mahatma Gandhi

Grading:

The grading period will open on **2/29/20** and will remain open until 11:59 pm on **3/3/29**.

During a grading round, each TRACTOR will be required to demonstrate a complete sequence of mining operations. The evaluation will take place with only a single TRACTOR on the field, competing and scoring in a match against a static dummy. During the match, your TRACTOR must demonstrate all abilities detailed in the Project Preview specification, with the addition of scoring by successfully positioning a MINER in an active region.

Evaluation for grading purposes will only occur during these rounds. If your TRACTOR 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.

> *I have ways of making money that you know nothing of.*
>
> *John D. Rockefeller*

Public Presentation:

This will take place on **3/4/20** starting at **7:00 pm** in the Atrium of Building 550.

> *I have a competition in me. I want no one else to succeed.*
>
> *Daniel Plainview*

Report:

Draft due on **3/9/20** by 4:00 pm. The final version with revisions is due by 5:00 pm on **3/13/20**.

> *I have always been fully persuaded that, through co-operation, labor could become its own employer.*
>
> *Leland Stanford*

Evaluation

Performance Testing Procedures:

One or more team members will operate the TRACTOR during the performance evaluation. A competition among the class' TRACTORs 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 **enter the URL to your site into a Google sheet that will be made available for that purpose**. 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 URL of your report be in the Google sheet 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 URL in the Google Sheet; update the URL if it changed) by 5:00 pm on 3/13/20. 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 TRACTOR 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 3/10/20.

☐ **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.

☐ **Peer Reviews** Completing both peer reviews on CATME are required components of the project. These reviews are not optional and the project work will be considered incomplete unless the reviews are completed by the due dates.

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[3]. 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.

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:

Anchor Electronics in Santa Clara	J&M Hobby House in San Carlos
Jameco in Belmont	TAP Plastics in San Mateo

Gems of Wisdom:

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

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[3]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.

Purpose:

The primary purpose of the Synchronized Permitting and Usage Designator (SPUD) is to act as a gateway to the field infrastructure to allow your TRACTOR to request information about the state of the game.

Connection Interface

Connector:

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

Pinout:

Pin	Name	Function
1	V_{dd}	Power to the SPUD; 3.3 V @ 100 mA
2	SDI	Serial Data Into the SPUD
3	SDO	Serial Data Out of the SPUD
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 SPUD

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 SPUD uses a synchronous serial signaling method to transfer data. The signaling method is compatible with SPI communications, with the SPUD 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 SPUD, while the SDI line represents serial data into the SPUD.

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

Data Exchange Specification

Memory Map:

The SPUD stores status about the game in a series of internal registers. These registers are laid out as defined in Table 2. Throughout, Corporation 1 refers to Carryer-Kenny Holdings (CKH), and Corporation 2 refers to Gumerlock Heavy Industries (GHI). The remainder of this section describes the register contents in detail.
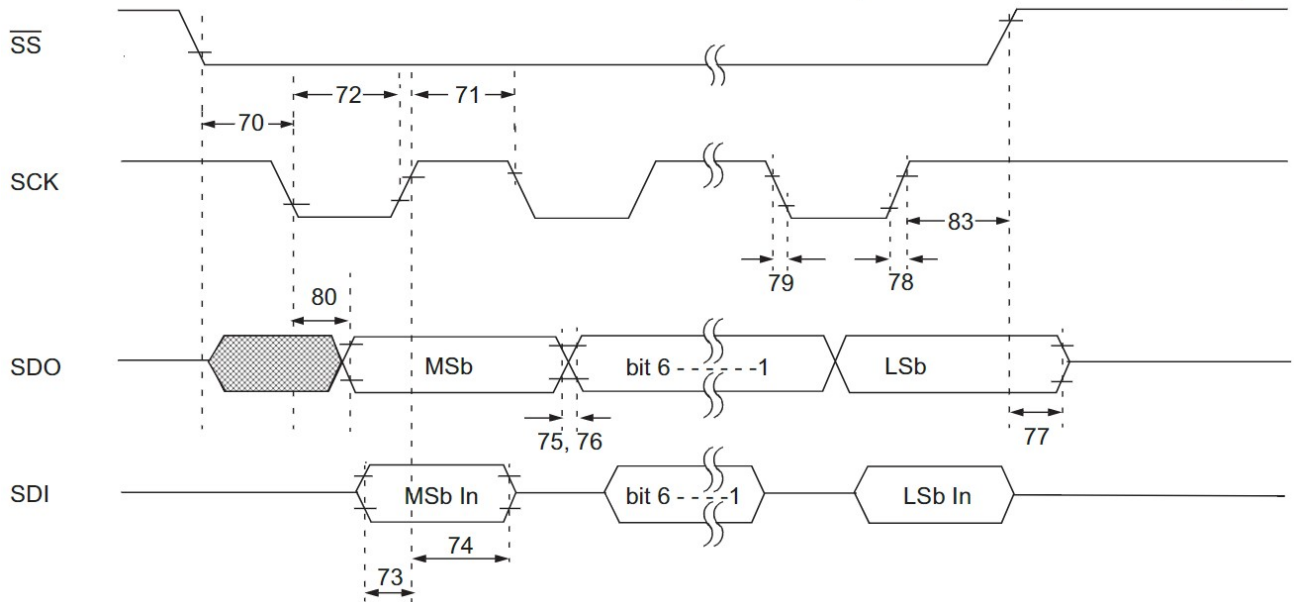
Figure 1: SPUD SPI timing diagram.

Param No.	Symbol	Characteristic		Min	Typ	Max	Units	Conditions
70*	TssL2scH, TssL2scL	$\overline{SS}\downarrow$ to SCK↓ or SCK↑ input		T_{CY}[a]	—	—	ns	
71*	TscH	SCK input high time (Slave mode)		T_{CY} + 20	—	—	ns	
72*	TscL	SCK input low time (Slave mode)		T_{CY} + 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	$\overline{SS}$ ↑ after SCK edge		1.5T_{CY} + 40	—	—	ns	

* These parameters are characterized but not tested. [a]T_{CY} = 33μS

Table 1: SPUD SPI timing values.

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
00h	STATUS	—	—	—	—	—	—	MOS1	MOS0
01h	C1MLOC1	LG	WFLG	BFLG	UFLG	LOC3	LOC2	LOC1	LOC0
02h	C1MLOC2	LG	WFLG	BFLG	UFLG	LOC3	LOC2	LOC1	LOC0
03h	C2MLOC1	LG	WFLG	BFLG	UFLG	LOC3	LOC2	LOC1	LOC0
04h	C2MLOC2	LG	WFLG	BFLG	UFLG	LOC3	LOC2	LOC1	LOC0
05h	C1RESH	Corporation 1 Resources High Byte							
06h	C1RESL	Corporation 2 Resources Low Byte							
07h	C2RESH	Corporation 1 Resources High Byte							
08h	C2RESL	Corporation 2 Resources Low Byte							
09h	PUR1	C2PMT3	C2PMT2	C2PMT1	C2PMT0	C1PMT3	C1PMT2	C1PMT1	C1PMT0
0Ah	PUR2	N2PMT3	N2PMT2	N2PMT1	N2PMT0	N1PMT3	N1PMT2	N1PMT1	N1PMT0

Table 2: SPUD Registers Summary

STATUS: Mining Operations Status Register

—	—	—	—	—	—	MOS1	MOS0
bit 7							bit 0

bit 1-0   **MOS<1:0>:** Mining Operations Status
         00 = Waiting for permits
         01 = Permits issued
         10 = Sudden death
         11 = Permits expired

CnMLOCk[1]: Corporation n MINER k Location Register

LG	WFLG	BFLG	UFLG	LOC3	LOC2	LOC1	LOC0
bit 7							bit 0

     The four CnMLOCk registers describe the status of the MINERs. n and k correspond to the corporation number and miner number, respectively, and each take values of 1 or 2.

bit 7   **LG:** Location Good
         1 = The location specified by LOC<3:0> is accurate.
         0 = The location specified by LOC<3:0> should not be trusted. Check WFLG, BFLG, and UFLG for status of this MINER. LOC<3:0> may be in any state.

bit 6   **WFLG:** White Detection Flag
         1 = The MINER has detected it is over a white area between regions.
         0 = The MINER is not over a white area.

bit 5   **WFLG:** Black Detection Flag
         1 = The MINER has detected it is over the tape.
         0 = The MINER is not over the tape.

bit 4   **UFLG:** Unknown Location Flag
         1 = The MINER is currently over an area that cannot be determined to be a valid location, the tape, or an inter-region space.
         0 = The MINER is currently over an area that is indicated by LG, WFLG, or BFLG.

bit 3-0   **LOC<3:0>:** MINER Location
         See Table 3 for a mapping of 4-bit codes to regions.

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[1] Only one of the flags in CnMLOCk<7:4> will be set for any read of this register.

Region	1	2	3	4	5	6	7	8
Code	0000	0001	0010	0011	0100	0101	0110	0111
Region	9	10	11	12	13	14	15	16
Code	1000	1001	1010	1011	1100	1101	1110	1111

Table 3: Codes for Regions

CnRESH/CnRESL: Corporation n Resource Level Registers

CnRES15	CnRES14	CnRES13	CnRES12	CnRES11	CnRES10	CnRES9	CnRES8
bit 15							bit 8

CnRES7	CnRES6	CnRES5	CnRES4	CnRES3	CnRES2	CnRES1	CnRES0
bit 7							bit 0

bit 15-0   **CnRES<15:0>:** Resource Level
Resources collected by Corporation n, represented as a 16-bit unsigned integer.
CnRES<15:8> are stored in CnRESH and CnRES<7:0> are stored in CnRESL.

PUR1: Permit and Usage Register 1

C2PMT3	C2PMT2	C2PMT1	C2PMT0	C1PMT3	C1PMT2	C1PMT1	C1PMT0
bit 7							bit 0

bit 7-4   **C2PMT<3:0>:** Corporation 2 Exclusive Permit Location
The location code for the active region exclusive to Corporation 2. See Table 3 for a mapping of 4-bit codes to regions.

bit 3-0   **C1PMT<3:0>:** Corporation 1 Exclusive Permit Location
The location code for the active region exclusive to Corporation 1. See Table 3 for a mapping of 4-bit codes to regions.

PUR2: Permit and Usage Register 2

N2PMT3	N2PMT2	N2PMT1	N2PMT0	N1PMT3	N1PMT2	N1PMT1	N1PMT0
bit 7							bit 0

bit 7-4   **N2PMT<3:0>:** Neutral Permit Location 2
The location code for the second active region available to both corporations. See Table 3 for a mapping of 4-bit codes to regions.

bit 3-0   **N1PMT<3:0>:** Neutral Permit Location 1
The location code for the first active region available to both corporations. See Table 3 for a mapping of 4-bit codes to regions.

Reading Registers:
Communication can be transferred from the SPUD to your TRACTOR by reading particular registers from the SPUD. The first byte from the TRACTOR to the SPUD will be a read register command. This will always be followed by two bytes of 0x00. The value returned from the SPUD during this transfer will be 0x00 in response to the read register command, followed by 0xFF, and finally the contents of the requested register. The read register command byte is specified in the following table:

RR: Read Register

1	1	0	0	ADR3	ADR2	ADR1	ADR0
bit 7							bit 0

bit 3:0   **ADR<3:0>:** Register Address
The address of the register to read, as specified in Table 2.

Power-on and Reset Behavior:

Initially, after power on or a reset, the SPUD will return `0xFF` in response to any command until such time as the SPUD is internally initialized.

Command Timing:

The interval between two successive transfers from TRACTOR to SPUD should be at least 2 ms. The $\overline{\text{SS}}$ line must remain high for a minimum of 2 ms between successive transfers, and must be asserted during the entirety of a single command transfer (3 bytes).

Invalid Command Bytes:

If the SPUD receives an invalid command, it will respond to the invalid command byte by returning a series of `0xFF` bytes to the TRACTOR until the $\overline{\text{SS}}$ line is asserted for 2 ms.

Sample Byte Sequence:

TRACTOR to SPUD	`0xCA`	`0x00`	`0x00`
SPUD to TRACTOR	`0x00`	`0xFF`	`0xA3`

In these sequences, the TRACTOR reads the value of the PUR2 register. In this case, the returned value indicates that regions 4 and 11 are currently active for either corporation to collect resources from.

Physical Specifications

Dimensions:

The SPUD dimensions are 50 mm × 75 mm × 25 mm.

Revision History

Revision 0: First draft, out for review. (1/30/20)
Revision 1: Initial release. (2/6/20)