Hyperloop Power Supply and Generation

Project Proposal

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1.0 INTRODUCTION

1.1 Statement of Purpose

The idea of levitation in everyday vehicular movement has always been a symbol of a distant utopic future, however, this idea can become the first step in bringing it closer. The hyperloop project is not targeting a specific problem, but creating progress towards a major component in our everyday lives. Hyperloop will create a transportation module that will move faster than bullet trains, while being more energy efficient than the system implemented in the California railways. Besides adding these immediate benefits, Hyperloop can become a foundation to further research applied in this field.

Our project in particular is concerned in designing a reliable power supply capable of meeting the demanding needs posed by such a vehicle. We will provide power to the levitation, computing, and braking systems of the pod to ensure a smooth and safe operation.

1.2 Objectives

1.2.1 Goals & Benefits

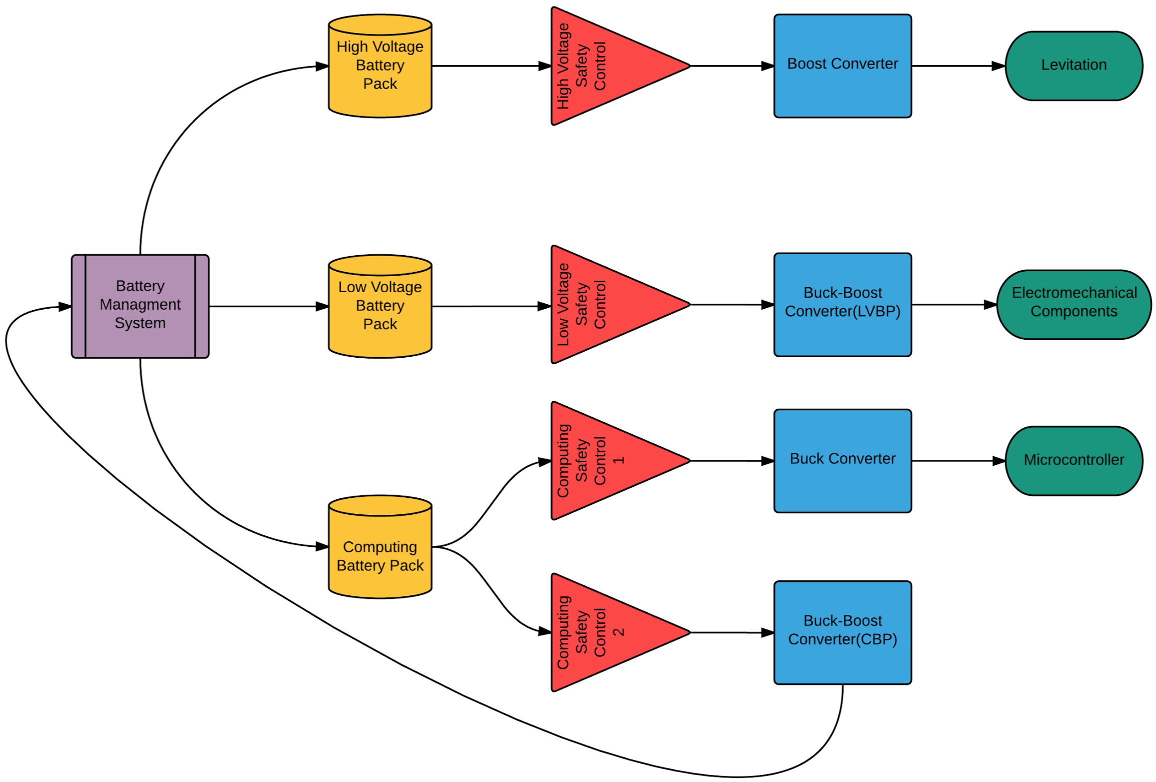
- Fastest public transportation system to date
- More energy efficient than public railways today
- Can create an overall faster transportation system for intermediate to far domestic travel

1.2.2 Functions and Features (Our specific part in Hyperloop)

- A stable power supply containing 24V, 12V, and 5V batteries
- Multiple power converters (Boost, Buck, and maybe Buck-Boost) to make sure loads are all at their stable voltage requirements
- Functional in a near vacuum (0.02 PSI)
- Endure a high vibration profile

2.0 Design

2.1 Block Diagram



2.2 Descriptions of Blocks

2.2.1 Battery Management System

The BMS will maintain cell balance, monitor State of Charge, Voltage, Current, and Temperature. It will also communicate these values to the microcontroller. In the final implementation of the Hyperloop pod, these values will be utilized by the computing subsystem (outside the scope of this project) to determine control of the pod.

2.2.2 High Battery Pack

This battery pack will provide power to the levitation system. It will be 36 V and must be capable of delivering approximately 30 kW continuously for 5 minutes. It will consist of multiple strings of 10 3.6 V rechargeable battery cells in series. Each string will be connected in parallel to obtain the desired power and energy density.

2.2.3 Boost Converter

A boost converter can step up the voltage of a power source, in this case it is the high battery power supply. This will be used for our High battery to power a load that requires approximately 72V with 21.6kW. We will be delivering a very high amount of current to this circuit due to our predicted load value being about .25Ω, thus giving us a current of 300 amps.

2.2.4 Low Battery Pack

This power supply will power our small onboard electromechanical components, for purposes such as brake actuation. It will be 14.4 V and must be capable of delivering 200 W continuously for 5 minutes. It will consist of 4 3.6V rechargeable cells in series.

2.2.5 Buck Boost Converter

This converter can be used to regulate voltage to a certain level, in this case our 12V output supply. With a 12V input supply we can regulate the output voltage to be constant using this converter. The 12V will be used for our battery management system. We expect a power consumption of no more than 5 W from the BMS.

2.2.6 Buck Converter

A buck converter can be used to step down the voltage of a source, we will be using it for when one of the batteries is powering some of the small system components of our circuit. This will be used to step down our low battery 12V to 5V to be used on several of the computing components. During our part of our testing phase and during this courses final presentation, we will use this to power our microcontroller. We expect a power consumption of no more than 15 W from the computing components.

2.2.7 Computing Battery Pack

This power supply will power our 12 V and 5 V systems. It will be 14.4 V and must be capable of delivering 20 W for 90 minutes. It will consist of multiple strings of 4 3.6V rechargeable cells in series. Each string will be connected in parallel to provide the needed energy capacity.

2.2.8 Microcontroller

The Microcontroller will be used to configure the duty cycle to specify what type of signal is being sent to our converters. This allows us to move away from a more difficult analog design to digital. The microcontroller will also collect data from the BMS as a proof of concept for later integration into the Hyperloop pod.

2.2.9 Safety Controls

There are controls implemented to ensure protections within our system. We will use fuses to protect against too high input currents and save our system from breaking down. These high ampere rated fuses will be used across all of our converters to ensure safety with all branches in our circuit.

3.0 Requirements and Verification

Requirements	Verification
Battery Management System 1. Balance cell voltages for all three packs	1. Follow manual for installation carefully, implementing all suggested testing procedures for that specific brand.
High Battery Pack 1. Discharge up to 21 kW continuous 2. Must be capable of delivering 21 kW for 5+ minutes	1. Connect fully charged battery pack to negative current source so that 20 W is drawn. 2. Run test 1 for 90 minutes at least 3 times.
Low Battery Pack 1. Discharge up to 200 W continuous 2. Must be capable of delivering 200 W for 5+ minutes	1. Connect fully charged battery pack to negative current source so that 200 W is drawn. 2. Run test 1 for 90 minutes at least 3 times.
Computing Battery Pack 1. Discharge up to 20 W continuous 2. Must be capable of delivering 20 W for 90+ minutes	1. Connect fully charged battery pack to negative current source so that 20 W is drawn. 2. Run test 1 for 90 minutes at least 3 times.
Buck Converter 1. Output 12 V +/- 5%, 5V +/- %5 2. Efficiency > %70	1. Input 14.4V and measure output voltage, input 0V and measure output voltage, input battery voltage at 20% SoC and measure output voltage. 2. Measure V and I for the inputs and measure V and I across the load.
Boost Converter 1. Output 72 V +/- 5% 2. Efficiency > %70	1. Input 36V and measure output voltage, input 0V and measure output voltage, input battery voltage at 20% SoC and measure output voltage. 2. Measure V and I for the inputs and measure V and I across the load.
Buck-Boost Converter 1. Output 12V +/- 5% 2. Efficiency > %70	1. Input 14.4V and measure output voltage, input 0V and measure output voltage, input battery voltage at 20% SoC and measure

	output voltage. 2. Measure V and I for the inputs and measure V and I across the load.
Microcontroller 1. Output several values of frequency between 10kHz to 1MHz +/- 1% 2. Output several duty ratio values between 0.1 to 0.9	1. Program the microcontroller to output a series of frequency signal from 10kHz to 1MHz. Connect the microcontroller to a digital multimeter to verify the correct output frequencies. 2. Program the microcontroller to output a signal with a series of duty ratio values from 0.1 to 0.9. Connect the microcontroller to an oscilloscope to verify the correct output signals.
Safety Controls 1. Must break circuit in the event of an unexpectedly high current.	1. We will buy extra fuses and confirm that they blow at their rated values. We will also test each fuse at our expected current for 90 minutes to ensure that they are properly rated for our application.
All components 1. Must endure a near vacuum environment 2. Must endure a high vibration profile	1. Use a vacuum chamber on each component individually, then together to ensure they may endure a vacuum at a no-load state. Depressurize to 0.02 PSI. 2. Use a poorly counterbalanced motor to generate vibrations. The complete system will be attached to this motor and must endure these vibrations. The power supply will also be at a no-load state.

3.3 Tolerance Analysis

Our tolerance analysis is simply a product of our error margins for the output power of our converter. An example below is for our high battery voltage pack boost converter.

Assuming a switching frequency of 100kHz

Boost Converter: The load will range from 315 amps to 285 amps given our 72±5% limit and thus 108 Watt pk-pk range of output power. We must be able to make sure our components and inductor can handle this level of change of current.

4.0 Cost and Schedule

4.1.1 Labor

Name	Hourly Rate(H_R)	Total Hours Invested(H_I)	Total = $H_I * H_R * 2.5$
Apurva	$30.00	190	$14,250.00
Lukasz	$30.00	190	$14,250.00
Will	$30.00	190	$14,250.00
Total			$42,750.00

4.1.2 Components/Parts:

Component/Part	Cost (* Quantity)	Link
Microcontroller	$55	http://www.ti.com/tool/beaglebk#buy
Resistors, Capacitors, Inductors, and Misc wires	~$40	-
Chassis	$47	http://www.directron.com/fdcacore1100bl.html
Fuse (Fast Acting)	$38.65 (x6) = $231.90	http://www.grainger.com/product/BUSSMANN-Very-Fast-Acting-1DC73
LED lights for indicators	$3	https://www.radioshack.com/products/green-led-with-holder-1?variant=5717557253
Fuse Holder	$28.10 (x6) = $168.60	http://www.grainger.com/product/

		BUSSMANN-Limiter-Fuse-Block-1DK98?opr=OAPD&pbi=1DC73
Fuse (Regular)	$0.45 (x8) = $3.60	http://www.mouser.com/ProductDetail/TE-Connectivity-Raychem/0402SFF200F-24-2/?qs=sGAEpiMZZMtxU2g%2f1juGqX82z3Yd6kPqgShtRSClmu8%3d
TOTAL	$549.10	

4.2 Schedule

Week	Task	Responsibility
7th February	-Finalize proposal -Prepare mock design review	-Lukasz -Apurva & Will
14th February	-Research and select components for power supply -Research and select microcontroller and power converter components -Finalize mock design review	-Will -Lukasz -Apurva
21th February	-Prepare design review -Purchase parts and begin design of buck and boost converters -Begin design of power supply	-Apurva -Will -Lukasz
28th February	-Finalize design review -Run initial test on power converters -Program microcontroller to provide signals for power converters	-Lukasz -Apurva -Will
6th March	-Assemble power converters within our power supply -Assemble other components within the power supply -Review assembly of the parts within the power supply	-Will -Lukasz -Apurva
13th March	-Run initial test on power supply -Run tests on individual	-Apurva -Will & Lukasz

	elements within the power supply	
20th March	-Continue testing components of the power supply -Prepare mock presentation	-Lukasz & Will -Apurva
27th March	-Optimize power supply components -Prepare Mock Presentation	-Will & Apurva -Lukasz
3rd April	-Assemble all components into a final enclosure -Run Tests on Final Project	-Apurva -Will & Lukasz
10th April	-Ensure Functionality -Fix Remaining Issues	All
17th April	-Prepare Demonstration -Prepare Presentation	All
24th April	-Prepare Final Paper -Finalize Demonstration -Review/Assist with demonstration	All
1st May	-Finalize Presentation -Lab Checkout, Review Final Paper -Finalize Final Paper	All

Piazza Proposal RFA:

Title: IlliniHyperloop Power Subsystem Design

Overall, our goal is to utilize 6 Arx Pax hover engines to provide lift for an ~260 kg pod for an estimated flight time of less than 20 seconds, along with functionality tests that may take up to 1 minute. From the specifications provided by ArxPax, we expect to consume 70 W/kg and have a ride height of ~5mm. This puts our total power consumption at 18kW. Our responsibility would be to implement and (significantly) refine the design that was established this past semester.
Our end-of-semester deliverables will be working levitation and power supply (battery) systems. The levitation system will powering a motor controller (provided by ArxPax) to generate lift using their hover engine technology. Alongside this, we will be powering a number of electromechanical components and sensors, whose expected power consumption will be provided by other teams. This at a minimum will require us to build two DC-DC buck converters and between one to six DC-DC boost converters to power several different voltage valued components in the system as well as providing the necessary power to lift the pod.

Finally, we will be concerning ourselves with safety and redundancy for our system to ensure smooth operation as well as a number of contingencies should something go wrong.

To demonstrate the effectiveness of our system, we will design and utilize a variety of test-benches in order to verify the proper operation of each mechanism before connecting them to other components. We will pay special attention to the DC-DC converters and battery packs we are constructing.

RFA 2.0:

Title: IlliniHyperloop Power Supply Design
Names: John Harley harley2, Lukasz Kosakowski (kosakow2), Apurva Shah (ashah13)

Description:

The University of Illinois has spent the past semester designing a pod for the upcoming Hyperloop competition. This vehicle will weigh 260 kg, travel through a vacuum at 250 mph, and have an acceleration profile of 2+ g's. As part of the design, Illini Hyperloop will be eschewing traditional wheels and opting for a magnetic levitation system. This levitation system will consist of 6 Arx Pax hover engines and is expected to consume over 18 kW, making up the primary electronic load of the vehicle.

For our senior design project we plan to design, build, and test a power supply capable of outputting 21 kW at 72 V, 200 W at 24 V, 10 W at 12 V, and 15 W at 5 V. The 72 V, 24 V and 12 V systems must be capable of being continuously powered for 5 minutes, while the 5 V system must be capable of being continuously powered for 20 minutes. This power supply will utilize multiple battery packs for redundancy, and will be designed to minimize weight without compromising safety. It must be cable of operating at 0.02 psi while undergoing potentially significant vibrations.

To achieve this goal, we will build a number of buck and boost converters. In the interest of not confining ourselves to a set number, we will define this number as one or more. That being said, we do not foresee having more than three battery packs and will certainly be creating at least one boost converter to step our DC voltage up to 72 V.

We will also designing the safety systems of the power supply. This will include at a minimum: one BMS (purchased), overcurrent protection, and arc prevention.

We have compiled a PAQ to answer some potential questions our RFA may have left unanswered.

Appendix Comment:

PAQ (Possibly Asked Questions):

Why did your power req’s suddenly change?

The pod’s design is not yet finalized, and will be undergoing at least one more round of changes. As such, we set the 72 V current rating at the maximum that six arx pax can consume. The 24 V, 12 V, and 5 V systems are fairly arbitrary, but should have enough overhead that any forseeable design changes in the pod will not exceed these limits.

Why five and twenty minutes?

This is also fairly arbitrary. Five minutes means that our levitation system may theoretically be used to help extract the pod from the track/tube should it come to a halt before reaching the end of the track. I want to stress that this scenario is hopefully unlikely, but this pod must have a contingency plan for every potential malfunction. The twenty minutes is so that the computing system may remain online even while the remainder of the pod functions are powered down.

How significant are these vibrations?

To put it simply, the Illini Hyperloop team has not yet determined this. That being said, it would not be unreasonable to incorporate a solution to isolate our power supply from vibrations if it will pose a significant problem on our design. This would be primarily designed by non-ECE students. What this means for our design is that we must consider vibrations when selecting and placing our components. Extra care must be taken for fragile components and mechanical relays will not be permitted.

How many is one or more?

We will be building at least one boost converter and one buck converter. We expect to be building two buck converters, and either one or six boost converters. If we build six, this will divide the power output of the 72 V system (21 kW) among the boost converters evenly. Six converters for six Arx Pax.

What about cooling?
Cooling will also be addressed by the Illini Hyperloop team, but it will require significant collaboration with students outside of this course so we have chosen to leave it outside the scope of our problem.

How will you show that this works? The course ends in April/May, but the competition is not until Summer.
To demonstrate the effectiveness of our system, we will design and utilize a variety of test-benches in order to verify the proper operation of each mechanism before connecting them to other components. We will pay special attention to the DC-DC converters and battery packs we are constructing. This will include both electrical tests to show that our supply works with the necessary range of loads, as well as physical tests to how that our supply will remain operational in the expected environment. We expect to have access to multiple departmental resources (Aero and Mechanical), so these physical tests shall not be limited by the resources available to the ECE department.

**We need a title: "IlliniHyperloop Power Subsystem Design" could be an option..
I believe our deliverables now include two DC-DC buck converters and one DC-DC boost converter, along with a battery implementation that will work with these converters.

HyperBoard™

Since the year 1986, the mysterious year of 2015 had promised many wonders, one of the most exciting being the hoverboard. Unfortunately, there has not been an adequate model that could make this prophecy real. We will now try to create a simple hoverboard levitation system using a multitude of various concepts in conjunction to create a stable lifting and balancing system capable of holding up to 100kg on a metal floor.

Main Concepts Used:

Fields and Waves: The primary method of lifting the board off of the ground will be through magnetic levitation. Since our track is metal we can create a current around the magnets in the board in order to do this. Since people obviously varying in weight, this current will have to be controlled by a digital control system.

The exact technologies we plan to use to accomplish this goal have already been pioneered by Arx Pax and, on a more basic level, Inductrack. The concept of this relies on magnetic halbach arrays, which use permanent magnets to create a sinusoidal magnetic field.

Power Electronics(Designing a Power Converter): Our method for creating a self-adjusting balance on the board is to create a power converter which connects from our main power source(initially batteries, but will attempt wireless in order to save weight) to multiple turbines on the board that will generate wind. This converter will be driven by the Gate driver with a digital control and will step up/down the power going through the turbines depending on the situation.

Digital Control/Logic Through Sensor Inputs: The digital control of our system will be based on the input of multiple sensors on the board. These infrared sensors will detect the distance the board is from the ground and allow the digital control to change the turbines and magnetics accordingly.

Deliverables:

Radial Halbach Arrays: Each radial array will consist of a 3d printed housing and a number of neodymium magnets. The radial array will be a wheel, the ‘spokes’ of which will contain the magnets. Each ‘spoke’ will have the magnets oriented in the next direction needed to create a halbach field.
Power Converter: see above

Chassis: Will design a basic chassis capable of handling human weight. Probably made of metal or wood. Will also look pretty.

Hoverboard: Final demo Product

Hardware Needed:
4 (Maybe 2) Radial Halbach arrays
3D printed plastic
Chassis materials
PCB, wires, chips for the power conversion circuit
Customized Inductor and specifically measured circuit components(i.e. capacitors, loads, and Gate Drivers)
Aluminum for our track
Microcontroller for computations
Sensors to detect near collisions(still in progress of looking at specifics)

Team members: (Will Harley) harley2, (Lukasz Kosakowski) kosakow2, (Apurva Shah) ashah13, Mention SPACEX: In August 2013, Elon Musk published a white paper detailing the concept of a high speed train that would travel through a near vacuum. This radical concept would enable mass transit to be faster, safer, cheaper, and greener than existing forms of transportation. In June 2015, SpaceX announced the Hyperloop Competition.

Our design would use spinning magnets to create magnetic fields that allow for levitation of our HyperBoard. Along with a stable base, we plan to lift 100kg for 5 minutes over a plate of aluminum.

Senior Design Proposal: Hoverboard

Lift 100 kg for 5 minutes over a plate of aluminum (get specs from hyperloop datasheet, or just use copper as it's less power intensive)

requirements:

- build levitation engine: radial halbach arrays
- build motor controller
- build power converter which is linked to the input of sensors that can detect distance
- program stability through some form of control system(digital control)
- buy: batteries, magnets, metal subtrack, motors, build materials

reach goal/ideas:

- use wireless power tech instead of batteries to power levitation
- use only one or two levitation engines (will require complex control system)

information:

- arxpax: http://www.google.com/patents/US20140265690
- halbach arrays: wikipedia
- inductrack: http://www.askmar.com/Inductrack/2000-4%20Magnetic%20Levitation.pdf, wikipedia

Probably won't work ideas:

- Use A/C current through base to lift a halbach array. Will need to vary Hz of signal relative to speed of halbach array.. may not be possible because: wavelength of halbach magnets need to equal wavelength of electrons (?), magnets may interfere with flow in a plate.

https://www.youtube.com/watch?v=BuWflDnAO9s

Requirements	Verification
Battery Management System This vessel will connect the multiple batteries to their appropriate loads 2. Balance cell voltages for all three packs	2. Follow manual for installation carefully, implementing all suggested testing procedures for that specific brand.
High Battery Pack This power supply will have our 24V battery and will supply the motor 3. Discharge up to 21 kW continuous 4. Must be capable of delivering 21 kW for 5+ minutes	3. Connect fully charged battery pack to negative current source so that 20 W is drawn. 4. Run test 1 for 90 minutes at least 3 times.
Low Battery Pack This power supply will power our 24 V systems 3. Discharge up to 200 W continuous 4. Must be capable of delivering 200 W for 5+ minutes	3. Connect fully charged battery pack to negative current source so that 200 W is drawn. 4. Run test 1 for 90 minutes at least 3 times.
Computing Battery Pack This power supply will power our 12 V and 5 V systems 3. Discharge up to 20 W continuous 4. Must be capable of delivering 20 W for 90+ minutes	3. Connect fully charged battery pack to negative current source so that 20 W is drawn. 4. Run test 1 for 90 minutes at least 3 times.
Buck Converter A buck converter can be used to step down the voltage of a source, we will be using it for when one of the batteries is powering some of the small system components of our circuit 3. Output 12 V +/- 5%, 5V +/- %5 4. Efficiency > %70	● Oscilloscope ● Multimeter ● Probes ● Variable Loads ● Waveform Generator 1. Input 24V and measure output voltage, Input 0V and measure output voltage 2. Measure V and I for the inputs and measure V and I across the load
Boost Converter A boost converter can step up the voltage of a power source, in this case it is the high battery power supply. This will be used for our 24V battery to power a load that requires approximately 72V 3. Output 72 V +/- 5%	● Oscilloscope ● Multimeter ● Probes ● Variable Loads ● Waveform Generator 1. Input 24V and measure output voltage, Input 0V and measure

4. Efficiency > %70	output voltage 2. Measure V and I for the inputs and measure V and I across the load
Buck-Boost Converter Will come from our low-voltage batteries. It will be used to	• Oscilloscope • Multimeter • Voltage/Current Probes • Variable Loads • Waveform Generator
Microcontroller Program a Microcontroller to configure the duty cycle to specify what type of signal is being send to our converters. This allows us to move away from a more difficult analog design to digital. 3. Output several values of frequency between 10kHz to 1MHz +/- 1% 4. Output several duty ratio values between 0.1 to 0.9	• Test Loads/Values • Run the code and actually compile it • Verify with waveforms and physical tests 1. Program the microcontroller to output a series of frequency signal from 10kHz to 1MHz. Connect the microcontroller to a digital multimeter to verify the correct output frequencies 2. Program the microcontroller to output a signal with a series of duty ratio values from 0.1 to 0.9. Connect the microcontroller to an oscilloscope to verify the correct output signals.