KRUPS Communication System

Critical Design Report

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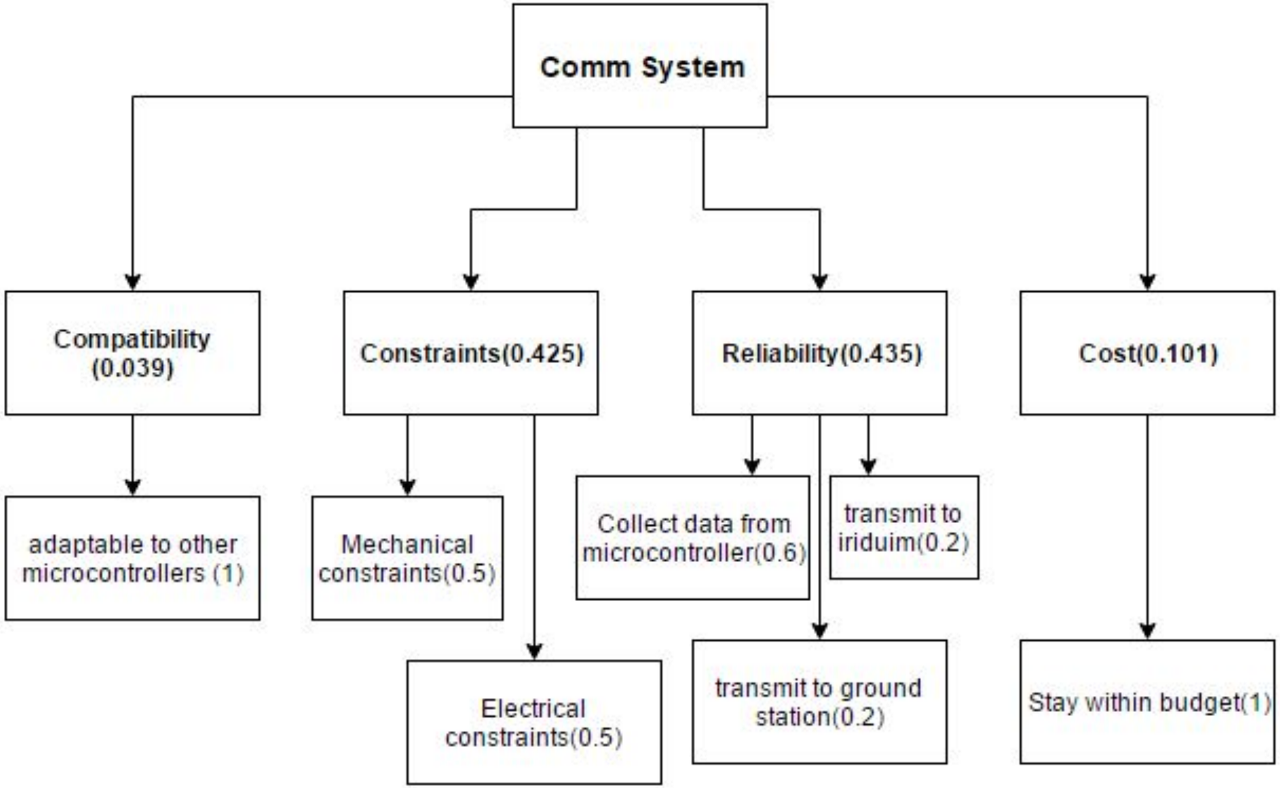
Objective

- Design, build, test, and integrate a communication system for the Kentucky Reentry Universal Payload System (KRUPS)
- Transmit data from a variety of instruments to both the Iridium network and a ground station
- Operate during a balloon launch in the Spring of 2017

Marketing Requirements

Requirement Number	Marketing Requirement
1	The communication system should ensure maintainability and be easily compatible with future methodology.
2	The communication system shall operate within a strict set of mechanical constraints.
3	The communication system shall operate within a strict set of electrical constraints.
4	The communication system shall continuously and reliably collect a variety of measurements from the microcontroller onboard KRUPS.
5	The communication system shall continuously and reliably transmit data to the Iridium Network
6	The communication shall continuously and reliably transmit data to the ground station.
7	The communication system should stay within the predefined project budget.

Objective Tree



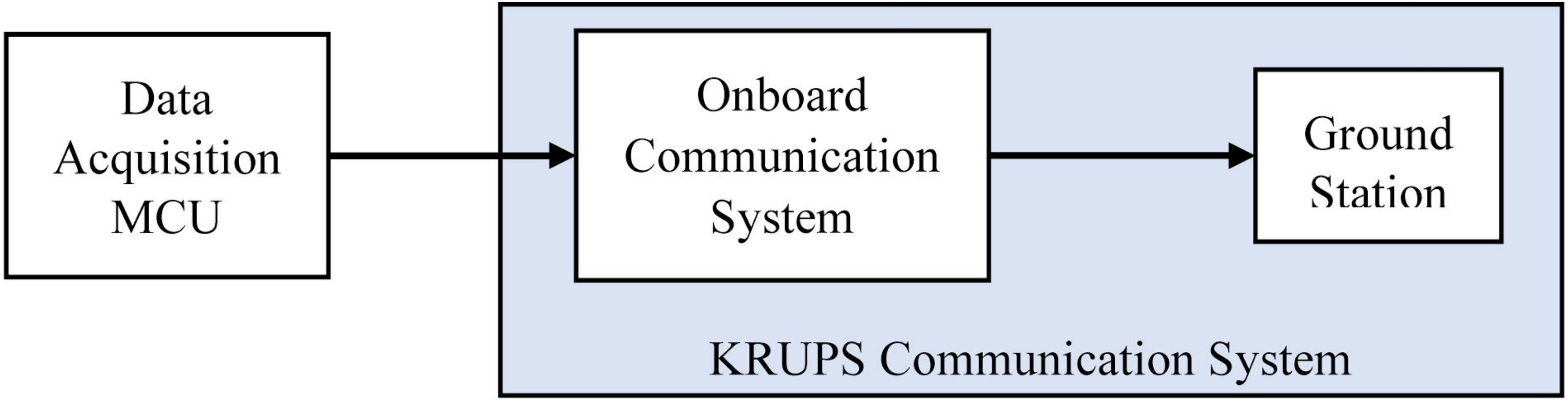
Engineering Requirements Summary

	Engineering Requirement	Mrkt. Req. Met	Rationale	Testing/Verification
3	The communication system’s dimensions shall not exceed 5 inches x 5 inches x 1 inch.	2	This is a size constraint requirement that makes sure this module fits in the capsule in the allocated location.	Team will measure using a digital caliper to measure dimensions.
4	The communication system’s total weight shall not exceed 1.5 lbs.	2	This is a weight constraint requirement. It affects location of center of gravity and entire mass of the probe.	Team will measure using a digital scale to measure the weight in kg to a 0.1g resolution.
5	The communication system shall be able to withstand a maximum of 85 degrees Celsius sustained temperature.	2	The operating temperature profile can vary with an upper limit of 85°C during demonstration.	Team will utilize a thermal vacuum chamber to verify operation at specified temperature.
8	The communication system shall operate using antennas shorter than 2.5 inches.	2	This is a size constraint requirement and plays a part in frequency allocation for the communication system.	Team will measure with a digital caliper to verify the antenna dimensions.
14	The communication system shall be able to transmit continuously for the duration of the 200-second reentry flight.	5, 6	The estimated time elapsed during drop test from altitude to ground level while continuously transmitting data during demonstration is less than this.	Team will perform a 200-second test transmission to confirm continuity.
17	The communication system shall receive a minimum of 50% of all data transmitted from either radio transceiver or Iridium network.	5,6	50% of the data collected is the minimum amount of data necessary to accurately represent the temperature profile of the KRUPS capsule during reentry.	Reception rate will be measured using predefined test data during balloon launch.

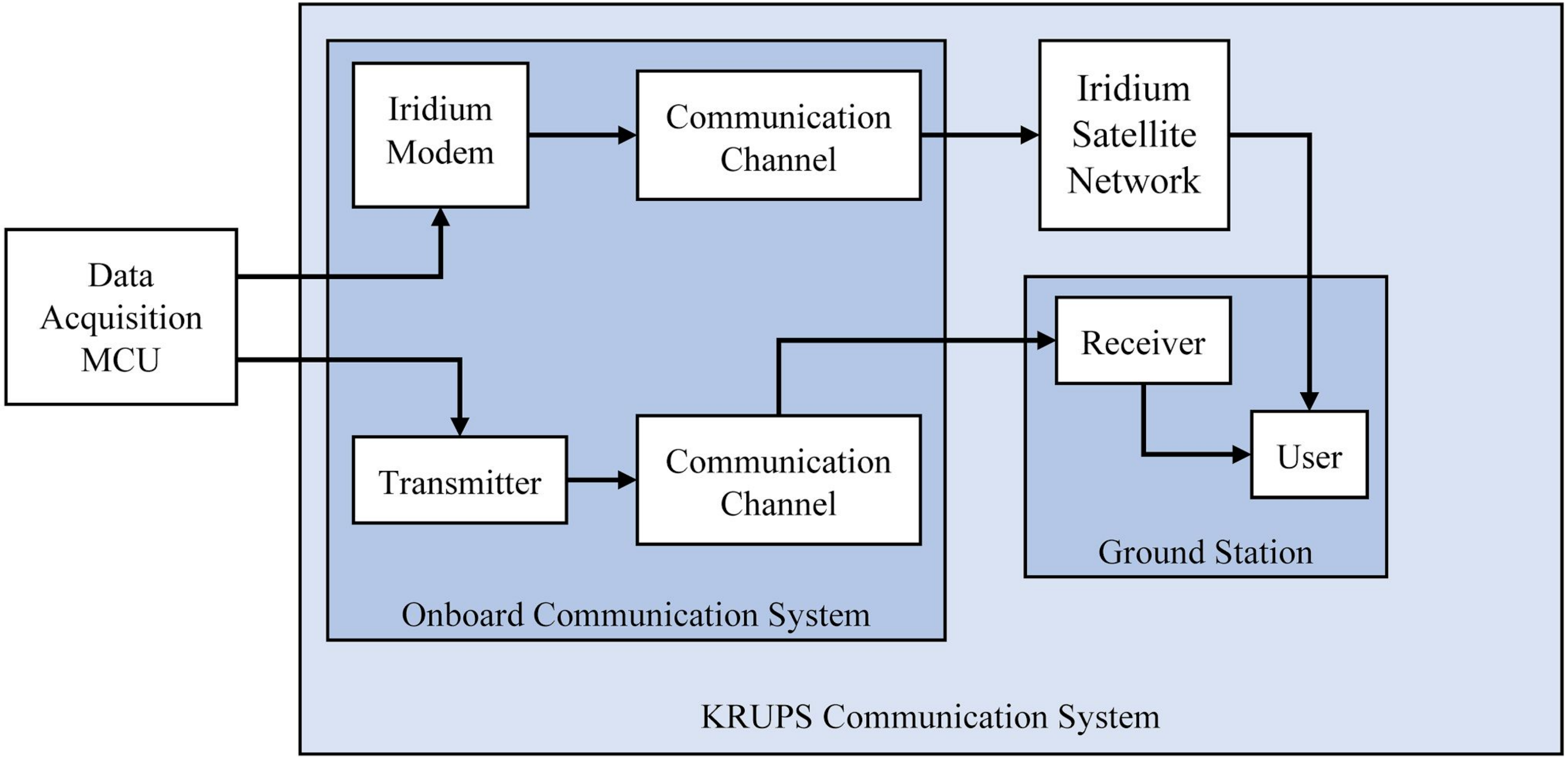
Project Impact

- **Economic**: Budget Constraints
- **Environmental**: Undesirable Weather
- **Political**: Comply with FCC Regulations
- **Manufacturability**: Physical and Electrical Constraints
- **Standards**: UART

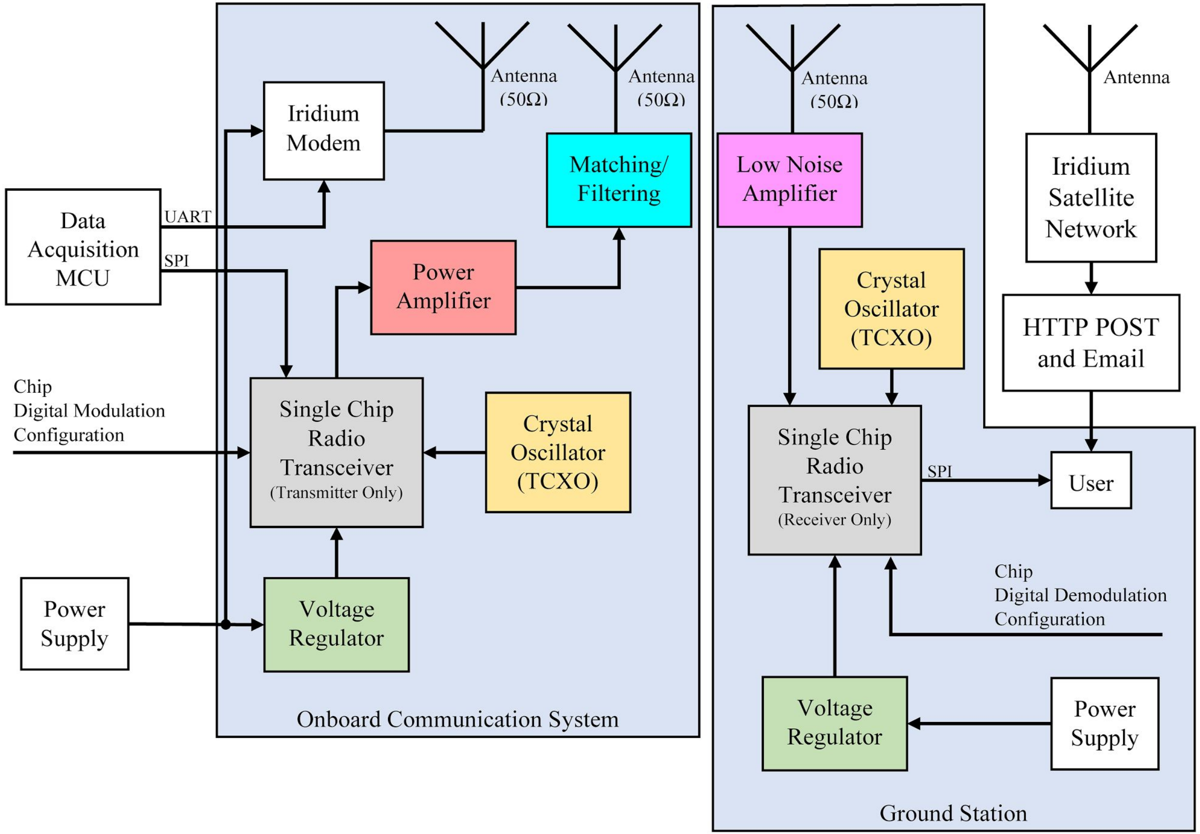
Functional Decomposition: Level 0



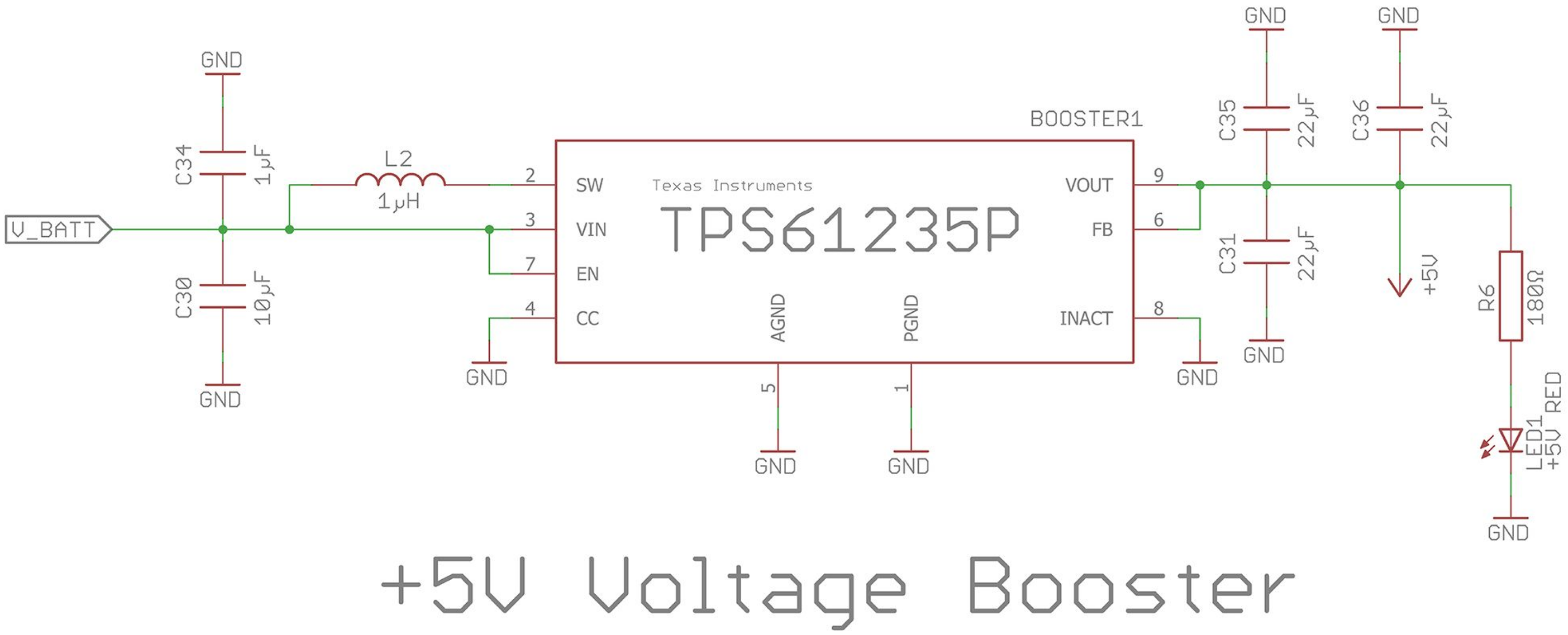
Functional Decomposition: Level 1



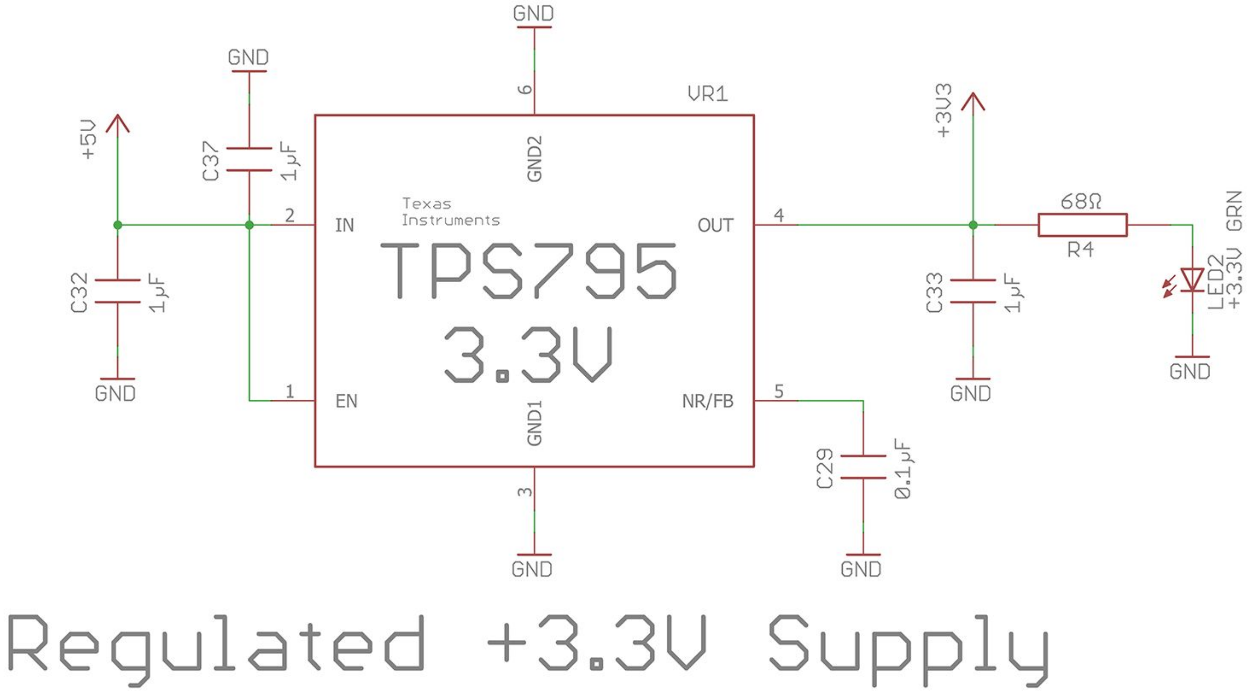
Functional Decomposition: Level 2



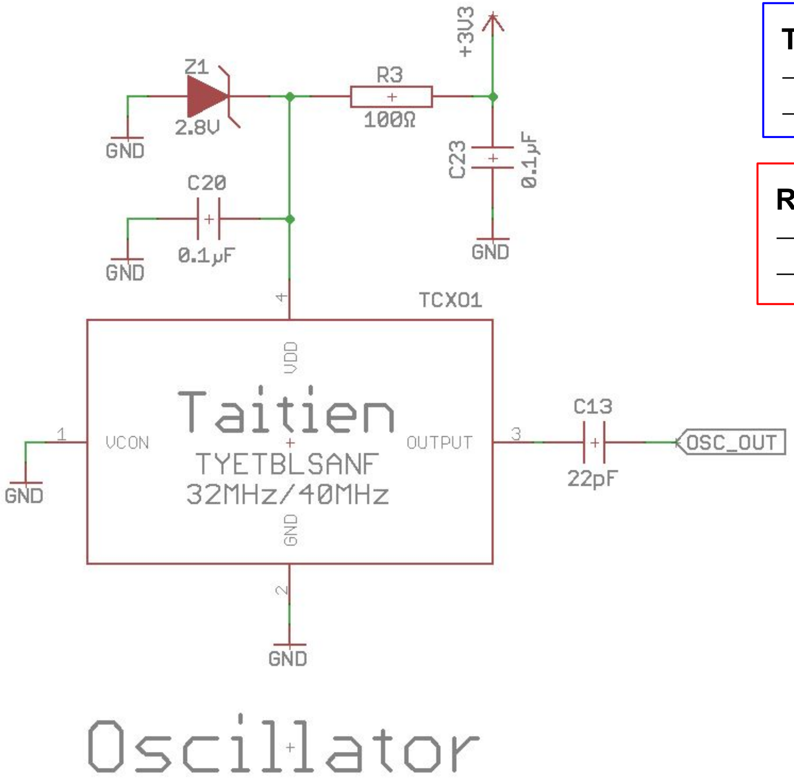
Voltage Booster Subsystem



Voltage Regulator



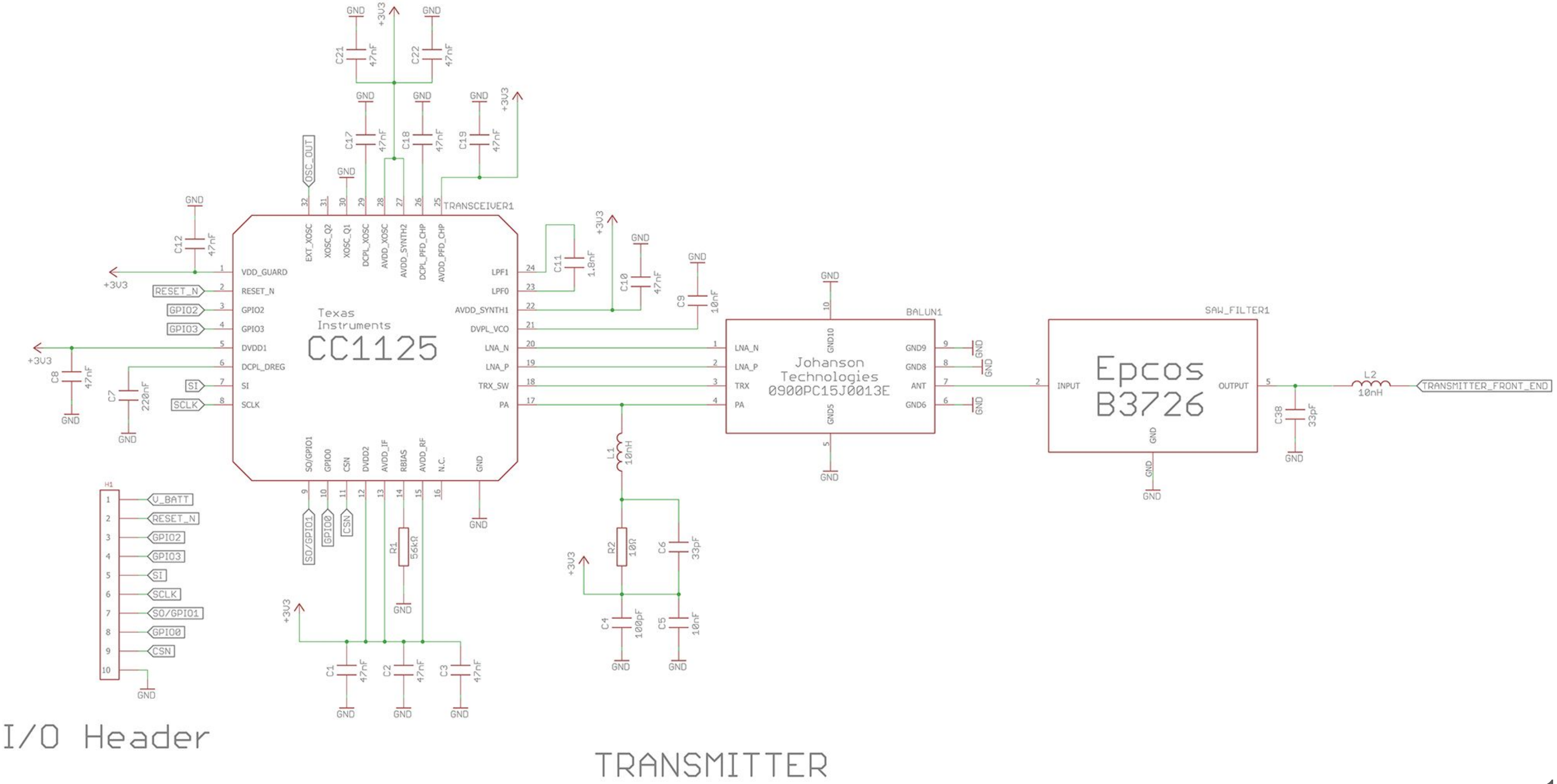
Temperature Compensated Crystal Oscillator



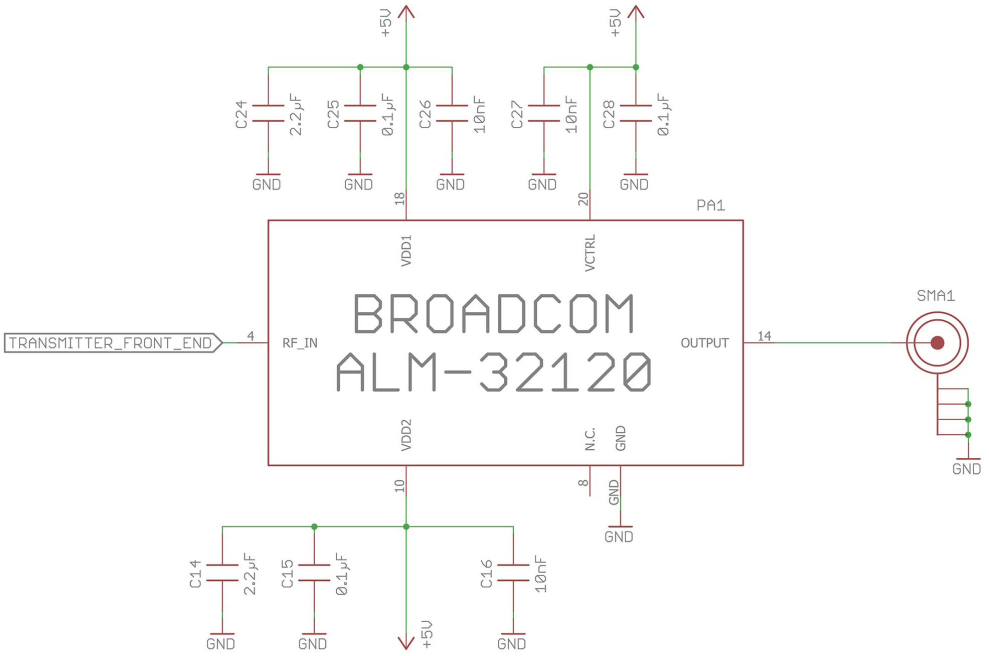
TRANSMITTER
→Use TI CC1125
→40Mhz TCXO

RECEIVER
→Use TI CC1120
→32Mhz TCXO

Transmitter

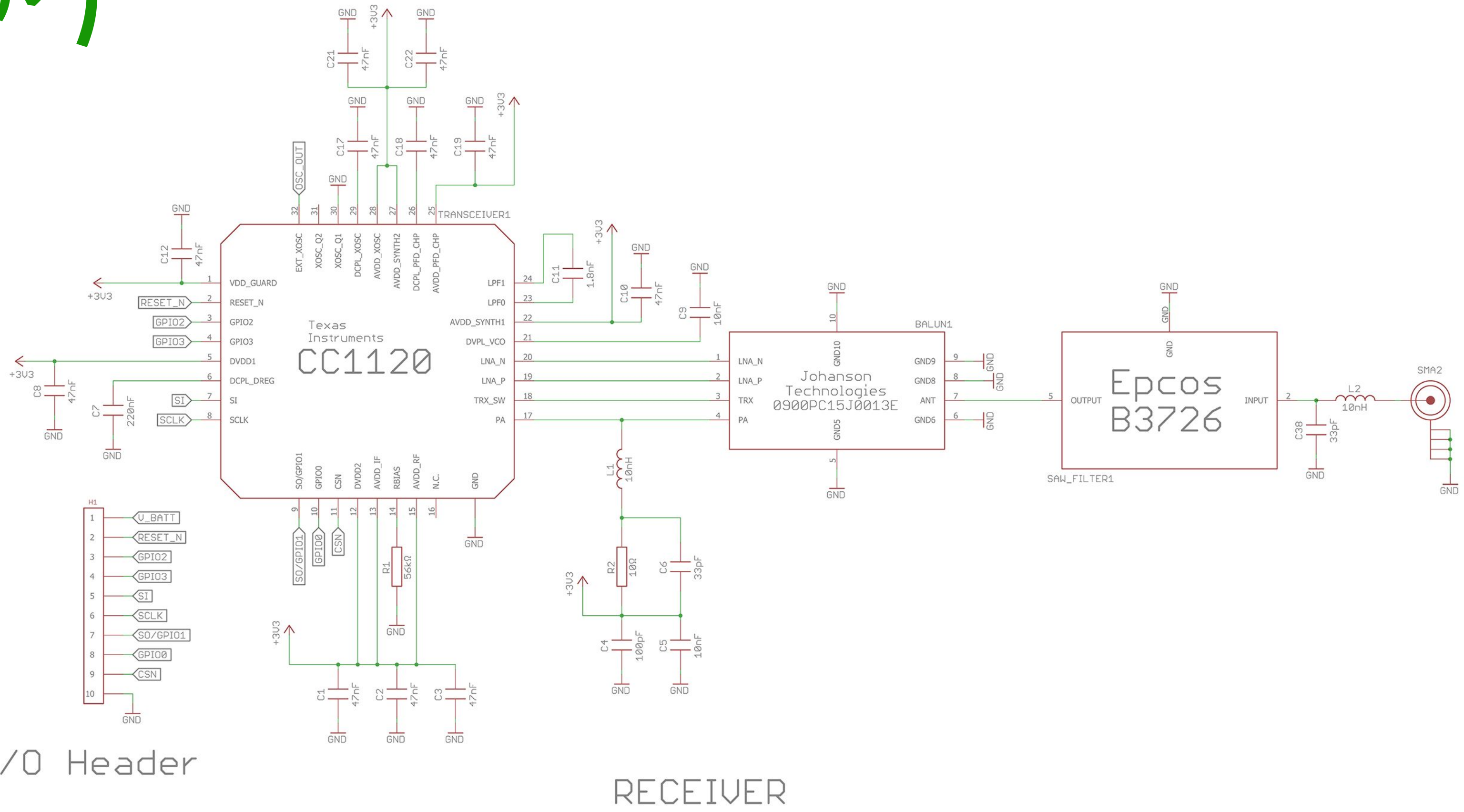


RF Power Amplifier

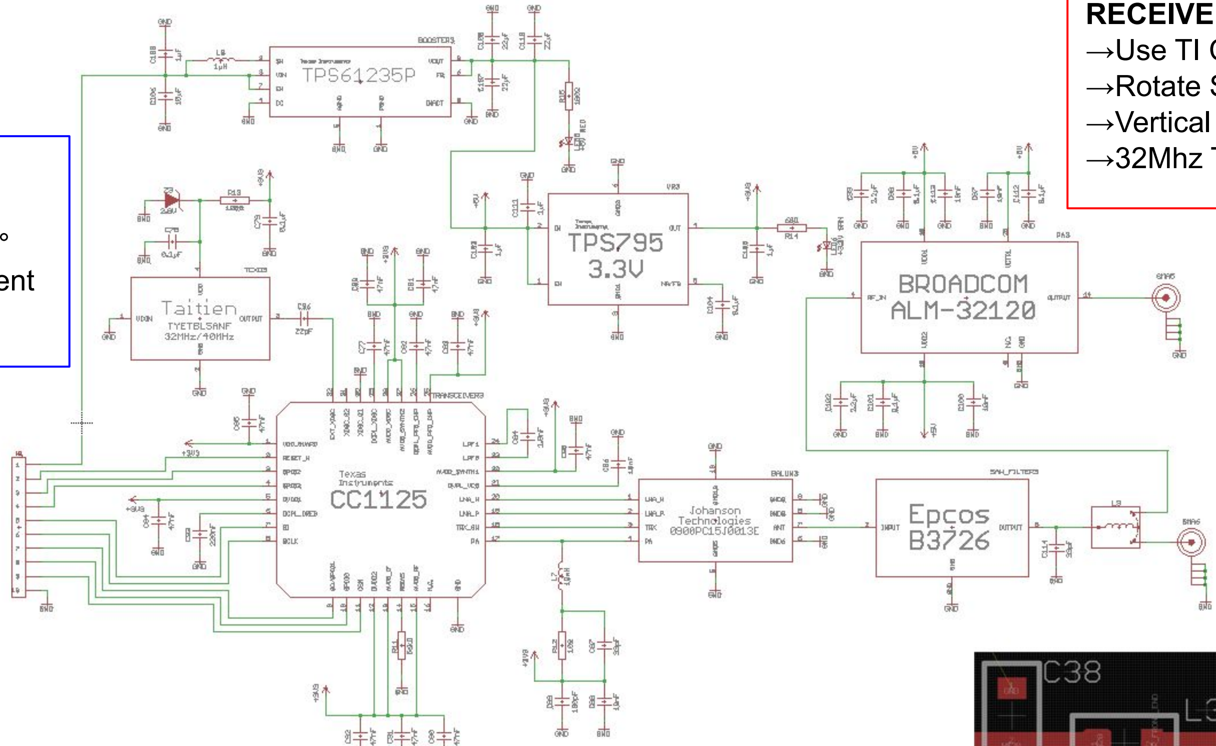


Transmitter Front-End

Receiver Schematic



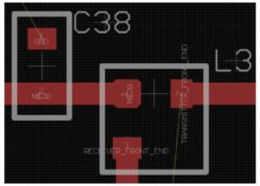
Complete Schematic



TRANSMITTER
→Use TI CC1125
→Rotate SAW_FILTER1 0°
→Horizontal 0° L3 placement
→40Mhz TCXO

RECEIVER
→Use TI CC1120
→Rotate SAW_FILTER1 180°
→Vertical 270° L3 placement
→32Mhz TCXO

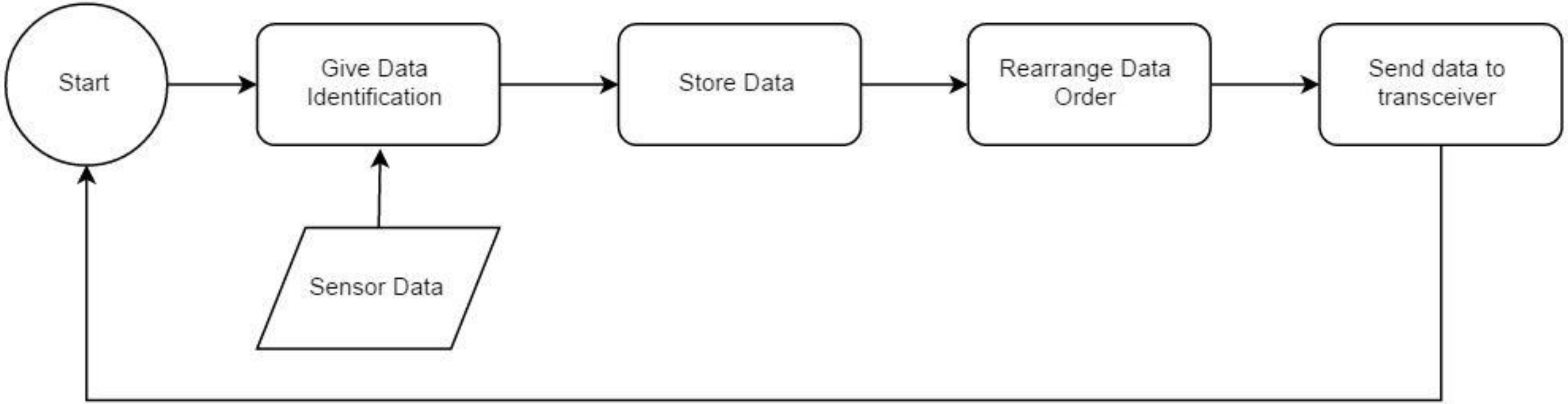
Placement of inductor L3 on PCB selects the radio front-end.



0°

270°

Final Software Decomposition



Integration, Verification, and Validation

- PCB Layout with Autodesk EAGLE
  - In the process of finalizing the layout
- Populate transceiver register configuration with SmartRF Studio
- Verify short-distance communication with test antennae
  - Continue increasing distance until problems arise

Work Breakdown Structure Summary

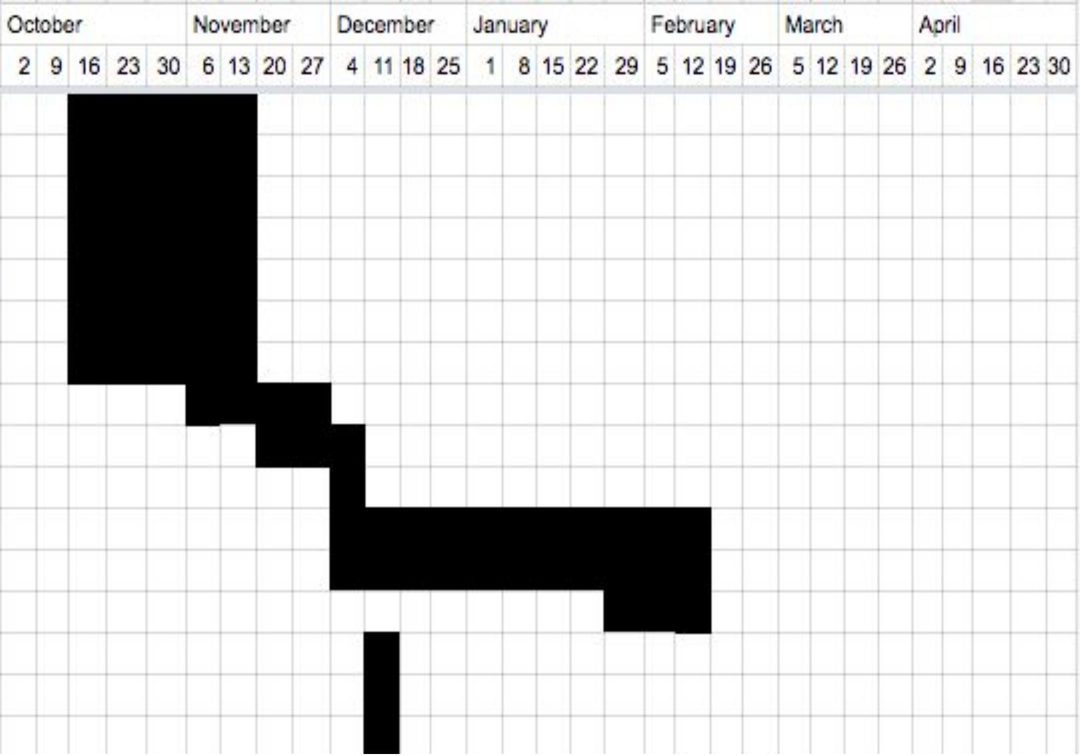
ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
1	Preliminary Research	Team members will conduct individual research on their selected sub-topic for the overall project	Individual Research Reports/ Hierarchy of design alternatives	28	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Internet	-
2	Preliminary Design	Team members will develop the preliminary design for the KRUPS communication system	Preliminary Design Report and Presentation/Multiple Functional Decomposition Diagrams	15	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Individual Research Reports, Internet, Requirements Report	1.1-1.6
3	Final Component Decisions/ Acquisition	Team members will make the final selections regarding components used for KRUPSComm, and purchase each of these parts	Physical possession of all components necessary for KRUPSComm project	17	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Individual Research, Data Sheets, Requirements Report, Internet	1.1-1.6, 2

Work Breakdown Structure Summary

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
4	Present at Senior Design Day	Team members will create a poster to showcase their progress and prepare a presentation to give at Senior Design Day 2016	Presentation and Poster	7	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Preliminary Design Report, eStudio, Printing Company	2
5	Assembly of Modules	Team members will use acquired components to being physically building the communication system	Fully assembled design	28	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Data sheets, online documentation, faculty members/sponsors	3
6	Integration/Testing of Modules	Team members will begin integrating the individual design modules together and testing that they satisfy the proper requirements	Test results that verify the functionality of each module of the KRUPS communication system	24	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Data sheets, online documentation, faculty members/sponsors	3, 5
7	Final Design Modifications/Final Test	Team members will finalize the design of the KRUPS Communication system in anticipation for the final test during the balloon launch	A complete project that is ready for integration into the KRUPS Capsule	35	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Data sheets, online documentation, results of performed tests, faculty members/sponsors	3,5,6

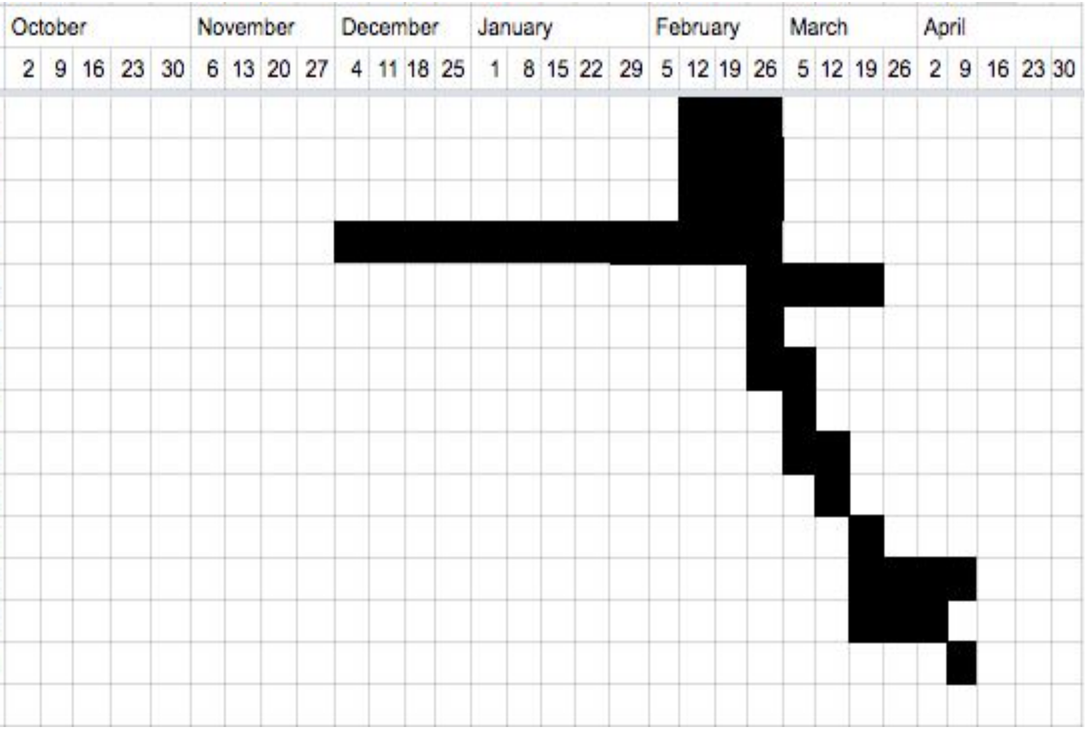
Gantt Chart

Activity	Days	Start	Finish
1. Preliminary Research	28	Oct. 12	Nov. 9
1.1 Frequency Allocation	28	Oct. 12	Nov. 9
1.2 Antennas	28	Oct. 12	Nov. 9
1.3 Modulation/Demodulation	28	Oct. 12	Nov. 9
1.4 Transmitter	28	Oct. 12	Nov. 9
1.5 Receiver	28	Oct. 12	Nov. 9
1.6 RF/Digital Communication	28	Oct. 12	Nov. 9
2. Preliminary Design	27	Nov. 2	Nov. 28
3. Final Component Decisions/Acquisition	17	Nov. 18	Dec. 18
3.1 Vendor Selection	1	Dec. 2	Dec. 2
3.2 Final Component Selection	3	Dec. 2	Feb. 12
3.3 PCB design/Fabrication	14	Dec. 4	Feb. 12
3.4 Place Order for Components	13	Jan. 29	Feb. 12
4. Present at Senior Design Day	7	Dec. 1	Dec. 7
4.1 Design Poster	4	Dec. 1	Dec. 4
4.2 Senior Design Presentation	1	Dec. 7	Dec. 7



Gantt Chart

Activity	Days	Start	Finish
5. Assembly of Modules	90	Dec. 4	Mar. 1
5.1 Assemble Onboard Communication System	21	Feb. 12	Mar. 1
5.2 Assemble Ground Station	21	Feb. 12	Mar. 1
5.3 Write software for microcontroller interface	90	Dec. 4	Mar. 1
6. Integration/Testing of Modules	24	Mar. 1	Mar. 25
6.1 Power Test	4	Mar. 1	Mar. 4
6.2 Iridium connection Test	4	Mar. 4	Mar. 7
6.3 Software Test	4	Mar. 7	Mar. 10
6.4 Transmit / Recieve Test	4	Mar. 10	Mar. 15
6.5 Thermal Test	4	Mar. 15	Mar. 19
6.6 Vibration Test	4	Mar. 19	Mar. 23
7. Final Design Modifications/Final Test	14	Mar. 23	Apr. 7
7.1 Penultimate Test	14	Mar. 23	Apr. 7
7.2 Balloon launch	1	Apr. 8	Apr. 8
7.3 Modifications Made	TBD	TBD	TBD



Cost Analysis

Components	Quantity	Price	Total Cost
50-Ohm SMA Connector	2	$6	$12
Test Whip Antenna	2	$9`	$18
Voltage Booster	2	$2.50	$5
SAW Filter	1	$2	$2
Balun	2	$1	$2
900MHz Power Amplifier	1	$1	$12
Crystal Oscillator	2	$3	$6
CC1125 Receiver / CC1120 Transmitter	2	$6	$12
Voltage Regulator	2	$3	$6
SMA Cable	2	$12.50	$25
Discrete Components (Resistors, Inductors, Capacitors)	~200	~$0.15 / Component	$40
PCB Fabrication	6 (3 potential revisions)	$7	$125
Shipping	-	$40	$40
Total Cost			**$346**

Individual Responsibilities

Team Member	Individual Responsibility
Abdulfattah Abu Taha	Circuit fabrication, Receiver Design
Zachary Davis	Organization, Transmitter/Receiver design, Technical Documentation
Tanbir Gill	Transmitter Design, RF Layout
Yuanzhen Guo	Antenna Design and Construction
Ajin Sunny	Testing Receiver and Transmitter Configurations
Evan Whitmer	Purchasing of Parts, Programming, Communication Protocols
All Members	Circuit Design, Programming, Circuit fabrication, Financial Decisions, Assembly, Testing

Summary

- Receiver and Transmitter Schematic
- Microcontroller interface software
- Ready to finalize layout and begin assembly
- Cost is within budget
- On track for final balloon launch

Question/Answer

Appendix Slides

KRUPS COMM Engineering Requirements 1-5

	Engineering Requirement	Mrkt. Req. Met	Rationale
1	The communication system should use SPI, UART, or I2C to interface with the microcontroller aboard KRUPS	1, 4	These are well established common protocols used to communicate with embedded systems.
2	The communication system should operate using 3.3 Volt logic for I/O.	1, 3	3.3V logic is chosen for general compatibility with minimal hardware for logic level translation.
3	The communication system's dimensions shall not exceed 5 inches x 5 inches x 1 inch.	2	This is a size constraint requirement that makes sure this module fits in the capsule in the allocated location.
4	The communication system's total weight shall not exceed 1.5 lbs.	2	This is a weight constraint requirement. It affects location of center of gravity and entire mass of the probe.
5	The communication system shall be able to withstand a maximum of 85 degrees Celsius sustained temperature.	2	The operating temperature profile can vary with an upper limit of 85°C during demonstration.
6	The communication system shall withstand 2 thermal cycles between -30 degrees Celsius and 85 degrees Celsius over a period of 24 hours.	2	This is a requirement to ensure reliability of the communication system.

Engineering Requirements 6-10

	Engineering Requirement	Mrkt. Req. Met	Rationale
7	The communication system shall withstand 20*g* acceleration in any orientation.	2	This is a requirement so the system can withstand acceleration during transport and descend.
8	The communication system shall operate using antennas shorter than 2.5 inches.	2	This is a size constraint requirement and plays a part in frequency allocation for the communication system.
9	The communication system shall consume less that 9 Ampere-hours for the duration of the 200-second re-entry flight.	3	Available power is a limited resource. This is also a power requirement constraint.
10	The communication system shall transmit data at a minimum rate of 97 bytes/second.	5, 6	This is a transmission requirement.
11	The communication system shall transmit data to the Iridium satellite at frequencies between 1616-1625 MHz.	5	This is an off the shelf iridium modem with predetermined working frequencies that have been recommended for use.

Engineering Requirements 11-16

	Engineering Requirement	Mrkt. Req. Met	Rationale
12	The communication system shall transmit at a maximum of 1 Watt to the ground station.	6	This is the maximum transmit power allowed for using open frequency bands that are unlicensed..
13	The communication system should stay within a $1500 budget.	7	This is a funding limit. It also ensures the communication system meets low cost requirement.
14	The communication system shall be able to transmit continuously for the duration of the 200-second reentry flight.	5, 6	The estimated time elapsed during drop test from altitude to ground level while continuously transmitting data during demonstration is less than this.
15	The communication system's ground station should be light and compact enough to be transported by one person.	2, 6	This ensures ground station is easily transportable which also has an additional benefit of being used to improve signal reception.
16	The communication system shall have the capability to enter a "sleep mode" which consumes less power than the operational mode.	3	This ensures the communication system conserves power since it is a limited resource.
17	The communication system shall receive a minimum of 50% of all data transmitted from either radio transceiver or Iridium network.	5,6	50% of the data collected is the minimum amount of data necessary to accurately represent the temperature profile of the KRUPS capsule during reentry.

Testability and Verification

Req. Num.	Engineering Requirement	Method for Testing
1	The communication system should use SPI, UART, or I2C to interface with the microcontroller aboard KRUPS.	Team will inspect specification sheet for radio transceiver to confirm.
2	The communication system should operate using 3.3 Volt logic for I/O	Team will use a mixed signal oscilloscope to check the timing and the voltage levels using test data.
3	The communication system's dimensions shall not exceed 5 inches x 5 inches x 1 inch.	Team will measure using a digital caliper to measure dimensions.
4	The communication system's total weight shall not exceed 1.5 lbs	Team will measure using a digital scale to measure the weight in kg to a 0.1g resolution.
5	The communication system shall be able to withstand a maximum of 85 degrees Celsius sustained temperature	Team will utilize a thermal vacuum chamber to verify operation at specified temperature.

Testability and Verification (cont.)

Req. Num.	Engineering Requirement	Method for Testing
6	The communication system shall withstand 2 thermal cycles between -30 degrees Celsius and 85 degrees Celsius over a period of 24 hours.	Team will utilize a thermal vacuum chamber to verify operation at specified extreme temperatures.
7	The communication system shall withstand 20*g* acceleration in any orientation.	Team will test with a shaker table to verify operation at specified acceleration level.
8	The communication system shall operate using antennas shorter than 2.5 inches.	Team will measure with a digital caliper to verify the antenna dimensions.
9	The communication system shall consume less that 18 Ampere-hours for the duration of the 200-second reentry flight.	Team will perform a test transmission for 200 seconds using 18Ah battery to verify.
10	The communication system shall transmit data at a minimum rate of 97 bytes/second.	Team will use a mixed signal oscilloscope to verify the data transmission rate.
11	The communication system shall transmit data to the Iridium satellite at frequencies between 1616-1625 MHz.	Team will inspect the specifications of the Iridium modem to verify transmission frequency.

Testability and Verification (cont.)

Req. Num.	Engineering Requirement	Method for Testing
12	The communication system shall transmit at a maximum of 1 Watt to the ground station.	Team will measure using a vector network analyzer to verify power levels.
13	The communication should stay within a $1500 budget.	Team will examine the budget to verify it remains within the limit.
14	The communication system shall be able to transmit continuously for the duration of the 200-second reentry flight.	Team will perform a 200-second test transmission to confirm continuity.
15	The communication system’s ground station should be light and compact enough to be transported by one person.	One member of the team will transport the ground station to the testing site.
16	The communication system shall have the capability to enter a “sleep mode” which consumes less power than the operational mode.	Team will measure power consumption levels using a multimeter.
17	The communication system shall receive a minimum of 50% of all data transmitted from either radio transceiver or Iridium network.	Reception rate will be measured using predefined test data during balloon launch.

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
1	**Preliminary Research**	**Team members will conduct individual research on their selected sub-topic for the overall project**	**Individual Research Reports/ Hierarchy of design alternatives**	**28**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Internet**	**-**
1.1	Frequency Allocation Research	Individual Research for Frequency Allocation for KRUPSComm	See Deliverable for ID 1	28	Zachary	Internet	-
1.2	Antenna Research	Individual research for antennas used for KRUPSComm	See Deliverable for ID 1	28	Yuan	Internet	-
1.3	Modulation/Demodulation research	Individual research for modulation/demodulation techniques for KRUPSComm	See Deliverable for ID 1	28	Ajin	Internet	-
1.4	Transmitter Research	Individual research for transmitters used for KRUPSComm	See Deliverable for ID 1	28	Gill	Internet	-

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
1.5	Receiver Research	Individual Research for receivers used for KRUPSComm	See Deliverable for ID 1	28	Abdul	Internet	-
1.6	RF and Digital Communication Research	Individual Research for RF/Digital Comm. protocol used for KRUPSComm	See Deliverable for ID 1	28	Evan	Internet	-
2	**Preliminary Design**	**Team members will develop the preliminary design for the KRUPS communication system**	**Preliminary Design Report and Presentation/Multiple Functional Decomposition Diagrams**	**15**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Individual Research Reports, Internet, Requirements Report**	**1.1-1.6**
3	**Final Component Decisions/ Acquisition**	**Team members will make the final selections regarding components used for KRUPSComm, and purchase each of these parts**	**Physical possession of all components necessary for KRUPSComm project**	**17**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Individual Research, Data Sheets, Requirements Report, Internet**	**1.1-1.6, 2**

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
3.1	Vendor Selection	Team will select which vendor to use for project components	Selection of component vendor	1	Evan	Vendor Websites	-
3.2	Component Selection	Team will make final decision regarding transceiver, antenna, power supply, etc.	Complete list of specific components needed for KRUPSComm	3	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Individual Research, Data sheets, Requirements Report	3.1
3.3	PCB Design/Fabrication	Team will design PCB and place order for delivery	Physical PCB	14	Evan, Gill, Zach	PCB design software	3.2
3.4	Place Order for Components	Team will place the order for each necessary component and wait for arrival	All selected components	10	Evan	Vendor Website	3.1, 3.2
4	**Present at Senior Design Day**	**Team members will create a poster to showcase their progress and prepare a presentation to give at Senior Design Day 2016**	**Presentation and Poster**	**7**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Preliminary Design Report, eStudio, Printing Company**	**2**

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
4.1	Design Poster	Team will design poster layout for Senior Design Day	Poster Design	4	Yuan, Gill	Image Editing Software	-
4.2	Senior Design Presentation	Team will present at Senior Design Day 2016	Full Presentation	1	Zachary, Yuan, Ajin, Gill, Abdul, Evan	eStudio	4.1
5	**Assembly of Modules**	**Team members will use acquired components to being physically building the communication system**	**Fully assembled design**	**28**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Data sheets, online documentation, faculty members/sponsors**	**3**
5.1	Assemble Onboard Communication System components	Team will solder all components for the onboard communication system onto the PCB	Physical transmit chain to be placed onboard KRUPS cmodule	21	Zachary, Ajin, Evan	Data sheets, online documentation, faculty members/ sponsors	3.3, 3.4,

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
5.2	Assemble Ground Station components	Team will solder all components for the ground station system onto the PCB	Physical Receive chain to be placed at ground station	21	Yuan, Abdul, Gill	Data sheets, online documentation, faculty members/ sponsors	3.3, 3.4
5.3	Write software for microcontroller interface	Design and write software for communication between microcontroller and communication system	Completed software to allow for proper interfacing	28	Evan, Zachary	Data sheets, Language Documentation	5.1
6	**Integration/Testing of Modules**	**Team members will begin integrating the individual design modules together and testing that they satisfy the proper requirements**	**Test results that verify the functionality of each module of the KRUPS communication system**	**24**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Data sheets, online documentation, faculty members/sponsors**	**3, 5**
6.1	Power Test	Team will test circuit operation when power is applied	Functional circuits with power applied	4	Gill, Abdul	-	5.1, 5.2

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
6.2	Iridium Connection Test	Team will test if the Iridium modem can properly communicate with the Iridium Satellite Network	Successful data transfer from Iridium Satellite Network	4	Ajin, Yuan	Iridium Developer's Guide	5.1, 5.3, 6.1
6.3	Software Test	Team will test that the written software allows the microcontroller to interface with the onboard transmitter.	Successful data transfer from microcontroller to onboard transmitter	4	Evan, Zachary	Datasheets, Language Documentation	5.1, 5.3, 6.1-6.2
6.4	Transmit / Receive Test	Team will test that data transmitted from the KRUPS module can be received at the ground station	Successful data transfer from onboard transmitter to receiver at ground station	4	Zachary, Gill, Evan	Data sheets	5.1, 5.2, 5.3, 6.1-6.3
6.5	Thermal Test	Team will test that all functionality of the communication system will be retained during thermal cycling.	-	4	Abdul, Yuan	Wallops Flight Center provided thermal profile	6.1-6.4

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
6.6	Vibration Test	Team will test that the communication system retains functionality after vibration test	-	4	Evan, Ajin, Abdul	Wallops Flight Center provided vibration profile	6.1-6.5
6.7	Power Draw Test	Team will test that the power consumption from the KRUPS communication system is below the specified maximum amount	Confirmation that system draws an acceptable amount of power.	4	Zachary, Yuan, Ajin, Gill, Abdul, Evan	-	6.1-6.6
7	**Final Design Modifications/ Final Test**	**Team members will finalize the design of the KRUPS Communication system in anticipation for the final test during the balloon launch**	**A complete project that is ready for integration into the KRUPS Capsule**	**35**	**Zachary, Yuan, Ajin, Gill, Abdul, Evan**	**Data sheets, online documentation, results of performed tests, faculty members/sponsors**	**3,5,6**

Work Breakdown Structure

ID	Activity	Description	Deliverables	Days	People	Resources	Predecessors
7.1	Penultimate Test	Team will conduct a final test of the communication system before the balloon launch	Successful transmission and reception of test data created for the penultimate test.	14	Zachary, Yuan, Ajin, Gill, Abdul, Evan	-	5, 6
7.2	Balloon Launch	Team will perform the balloon launch of the KRUPS capsule to ensure the proper operation of the communication system,	Successful transmission and reception of test data created for the balloon launch (either via Iridium satellite or via ground station receiver)..	21	Zachary, Yuan, Ajin, Gill, Abdul, Evan	FAA regulations,	5, 6, 7.1
7.3	Modifications Made	Team will analyze results from balloon launch and make any modifications to the design (as necessary)	A final, revised communication system intended to be used by the KRUPS team for a future launch.	TBD	Zachary, Yuan, Ajin, Gill, Abdul, Evan	Results from balloon launch/penultimate test	5, 6, 7.1-7.2