INTRODUCTION

The purpose of this project readiness package (PRP) is to outline the anticipated resources required for developing a communication subsystem which will be implemented on a CubeSat. A project aimed at designing, testing, and ultimately launching a CubeSat was proposed by the organization RIT SPEX; only the CubeSat's communication subsystem is considered for the following PRP. The remaining subsystems required for a successful CubeSat launch are detailed in other PRPs. Elements contained within this PRP include the customer requirements, a functional decomposition, potential concepts, engineering requirements, anticipated risks, project constraints, and the desired final deliverable related to communication. It's anticipated that this PRP will be utilized by RIT faculty in order to evaluate the project as a potential Multidisciplinary Senior Design (MSD) project by reviewing the challenges, scope, skills, and resources required in order to complete the project.

ADMINISTRATIVE INFORMATION

PROJECT NAME:	RIT SPEX: CubeSat communication subsystem	
PROJECT NUMBER:	R15301	
DESIRED START TERM / END TERM:	Fall 2017 / Spring 2018	
TECHNICAL FACULTY MENTOR:	Unknown	
OTHER SUPPORT:	Dr. Agamemnon Crassidis	
PROJECT GUIDE:	Unknown	
PRIMARY CUSTOMER:	Name:	Anthony Hennig
	Company:	RIT SPEX
	Email:	aih2400@rit.edu
SPONSOR:	No sponsor; funding required	

PROJECT OVERVIEW

Since the successful launch of Sputnik, the first artificial satellite, in 1957, outer space has been a burgeoning field filled with research and experimentation. However, despite RIT's nascent programs in biomedical engineering, sustainability, and microsystems engineering, there is no program devoted to space. Therefore, the goal of the RIT Space Exploration (SPEX) team is to create an organization that supports students and their research of space systems engineering so that RIT can integrate itself into outer space programs, research, and initiatives.

Figure 1. *Image of a completed CubeSat. Specifically, this is California Polytechnic State University's CP1 CubeSat [12].*

SPEX hopes to accomplish their goal by designing, testing, and launching a CubeSat. Furthermore, RIT SPEX desires their CubeSat to be accepted onto a NASA ELaNa launch in order to avoid the high costs associated with launching a satellite into space. NASA's ELaNa launch provides the opportunity for CubeSats to fly as auxiliary payloads on board a previously planned launch mission. CubeSats are relatively inexpensive miniature satellites, typically 10cm x 10cm x 10cm cubic in size that are designed to test a myriad of space system technologies. One of the

primary systems that a CubeSat must contain is a communication system; communication enables a CubeSat to receive instructions from the ground, and it also allows the CubeSat to relay collected data, including images and atmospheric conditions, to the controllers on the ground. Thus, the communication subsystem is crucial to the overall success of the CubeSat in researching a new technology.

Detailed Project Description

The information provided below is intended to provide sufficient detail to RIT faculty regarding the challenges, scope, skills, and resources required in order to complete the project. The goal of this section is to define what the project entails so that an informed decision can be made by RIT faculty regarding the implementation of the proposed CubeSat communication subsystem as a MSD project for 5th year engineering students.

A proposed timeline for all the PRPs related to developing a CubeSat is provided in Figure 2. The structure of the CubeSat must be developed prior to any other system. After developing the outer structure of the CubeSat, internal subsystems can begin development. It's expected that the power acquisition and attitude control systems can be developed concurrently. Likewise, it's expected that the communication and radiation protection systems can be developed simultaneously. It’s anticipated that the communication subsystem would be developed during the 2017-2018 academic year. Following the communication and radiation protection systems, the overall avionics of the CubeSat can be designed to ensure proper functionality between all subsystems. Lastly, vibration mitigation must be considered in the final PRP to ensure that the completed CubeSat will survive launch and possibly re-entry. Therefore, it’s expected that a complete design of all systems required for a successful CubeSat launch will be fully developed by the end of the 2019-2020 academic year.

Academic year	Team A	Team B
2015 - 2016	Structure	-
2016 - 2017	Power acquisition	Attitude control
2017 - 2018	**Communication**	Radiation protection
2018 - 2019	Avionics	-
2019-2020	Vibration mitigation	-

Figure 2. *Proposed timeline for PRPs associated with developing and launching a CubeSat. It’s anticipated that the communication subsystem be designed by a MSD team during the 2017-2018 academic year.*

Customer Requirement Number	General category	Importance	Description
CR1	Technology	Critical	Ability to communication from low earth orbit
CR2	Technology	Desirable	Components are housed in a single unit structure
CR3	Technology	Critical	Solar panels for generating power
CR4	Technology	Critical	Protect CubeSat from radiation
CR5	Technology	Critical	Survive launch vibrations
CR6	Technology	Desirable	Re-entry
CR7	Technology	Important	3-axis attitude control
CR8	Technology	Critical	Adequate battery storage capabilities
CR9	Technology	Important	Fits in a launch pod
CR10	Technology	Critical	Contains functional flight software
CR11	Technology	Critical	Contains nascent technology for testing
CR12	Technology	Critical	Create general layout of components
CR13	Funding	Important	Acquire proper funding
CR14	Funding	Desirable	Continue acquiring revenues through sponsors
CR15	Layout	Important	Get proposal accepted by NASA ElaNa launch
CR16	Layout	Important	Integrate RIT SPEX club into annual MSD projects
CR17	Layout	Important	Create roadmap for RIT SPEX
CR18	Layout	Important	Develop a launch guide
CR19	Layout	Critical	Risk reduction testing
CR20	Layout	Important	Complete component testing before proposal due date

Figure 3. *Table of customer requirements with associated criticality. The customer requirements specifically related to the communication subsystem are provided in the House of Quality shown in Figure 8. Customer requirements in the House of Quality deemed as "critical" were weighted as 5, "important" as 3, and "desirable" as 1.*

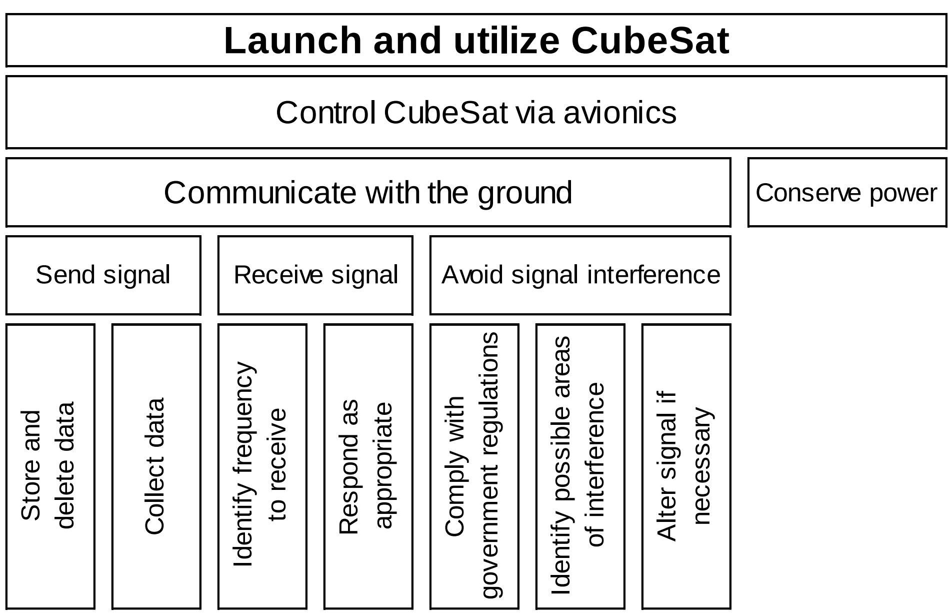

Figure 4. *Functional decomposition of CubeSat communication subsystem.*

Potentail antenna concepts	Potential radio concepts
monopole	Lithium - 1
dipole	Microhard MHX - 2400
patch	Stensat radio beacon
quadrifilar helicoidal	Pericle custom transponder
turnstile	Alinco DJ-C5
helical	Kenwood TH-D7
deployable	MaxStream Xstream 900 MHz OEM
	ISIS VHF downlink / UHF uplink transceiver

Figure 5. *Table of potential concepts for antennas and radios. Images of a few selected concepts are provided below in Figure 6.*

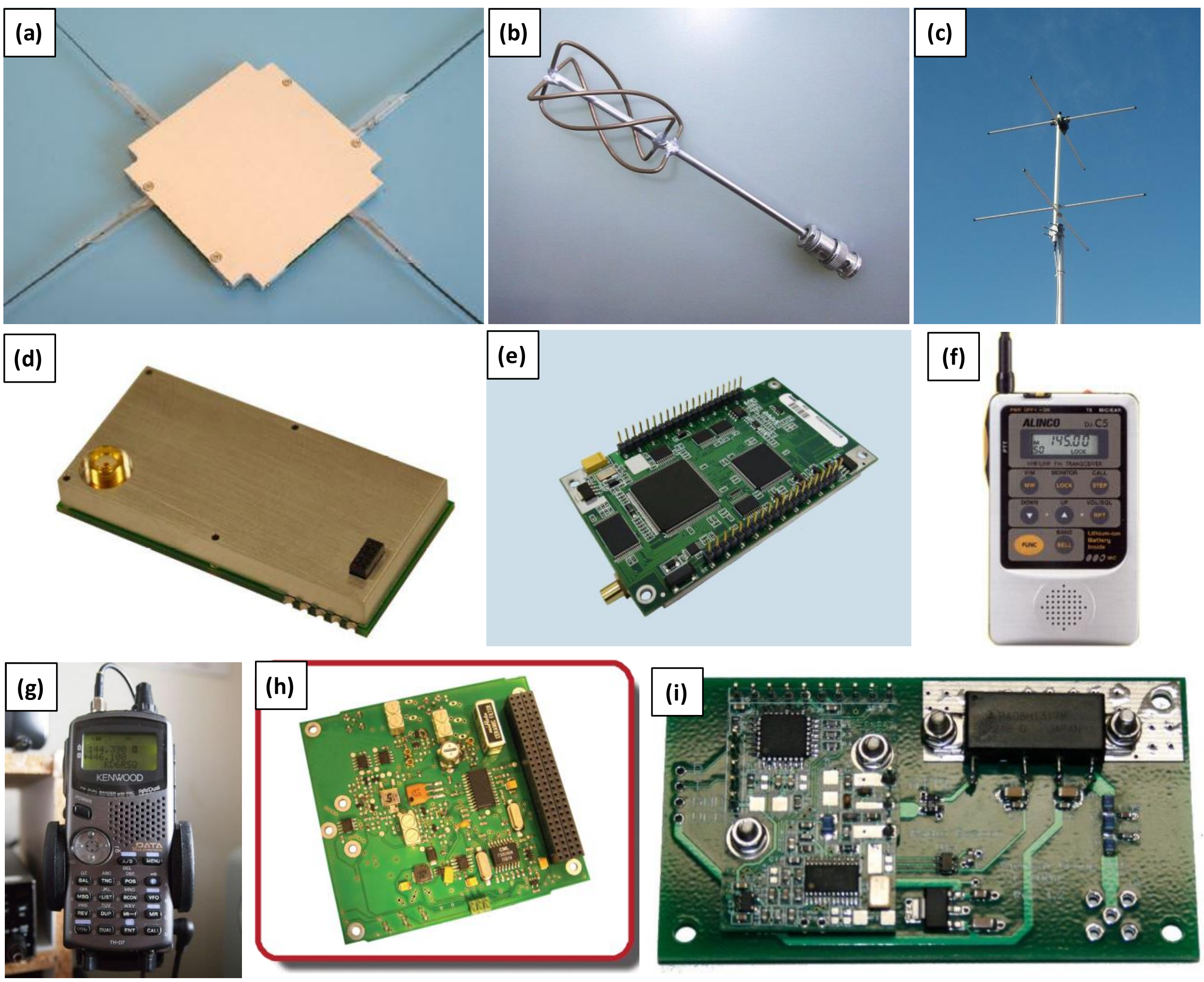

Figure 6. *Images of some potential transceiver and antenna concepts. The images are identified as follows:* **(a)** *ISIS deployable antenna [4]* **(b)** *quadrifilar helicoidal antenna [13]* **(c)** *turnstile antenna [14]* **(d)** *Lithium-1 radio [15]* **(e)** *Microhard MHX-2400 transceiver [16]* **(f)** *Alinco DJ-C5 handheld radio [17]* **(g)** *Kenwood TH-D7 handheld radio [18]* **(h)** *ISIS VHF downlink transceiver [5]* **(i)** *Stensat radio [19]*

Function	Engineering requirement(s)	Unit of measurement	Marginal value	Ideal value	Reference	Additional comments
Send signal	transmit signal an appropriate distance	[km]	1500	2000	[6]	the satellite will be in low earth orbit (LOE)
Collect & store data	measure, retrieve, and store data that the designers are seeking	[GB]	4	8	[8]	the required amount of data storage depends on the data that is being collected; 8 GB is typical for storing images
Receive signal	identify, receive, and interpret the signal sent from the ground	[MHz]	3	437	[8]	it's important that the signal received by the CubSat also complies with the interference avoidance metric
Conserve power	be able to operate for an extended time period	[days]	500	730	[6]	communication consumes a majority of the power that a CubeSat uses; therefore, this requirement is critical
	use limited power for communication purposes to allow for other functions	[mW]	100	100		
Comply with government regulations	submit an engineering proposal to the FCC outlining power requirements, flight specifications, and failure analysis	[Yes/No]	Yes	Yes	[6]	the frequency of the signal must comply with government regulations; a license is required in order to fulfill this metric
Avoid signal interference	possess unique communication frequency and comply with government regulations	[MHz]	3	437	[8]	a majority of academic satellites are required by the US government to operate at this frequency

Figure 7. *Engineering metrics specifically associated with the communication subsystem of a CubeSat.*

		Engineering metrics						
Customer requirements	**Customer weights**	transmit signal an appropriate distance	measure, retrieve, and store data that the designers are seeking	identify, receive, and interpret the signal sent from the grou	be able to operate for an extended time period	use limited power for communication purposes to allow for other functions	submit an engineering proposal to the FCC outlining power requirements, flight specifications, and failure analysis	possess unique communication frequency and comply with government regulations
Communicate from Low Earth Orbit	5	5	2	3	1			3
Adequate battery storage	5		2			5		
Components are housed in a single unit structure	1			2				2
Acquire proper funding	3				2		5	1
Get proposal accepted by NASA ElaNa launch	3				2		5	1
	Technical target	1500	8	437	730	100	Yes	437
	Units	km	GB	MHz	days	mW	-	MHz
	Raw score	25	20	17	17	25	30	23
	Relative weight	16%	13%	11%	11%	16%	19%	15%

Figure 8. *House of quality that compares the customer requirements in Figure 3 to the engineering metrics in Figure 7.*

Risk number	Risk	Cause	Effect	Likelihood (3=most likely 1=least likely)	Severity (3 = most severe 1=least severe)	Importance (9=most important 1=least important)	Action to mitigate	Action to remediate	Owner (individual who takes action if necessary)
1	**Comm. subsystem is damaged during launch**	Insufficient vibration testing or a collision with foreign particles during launch	CubeSat is unable to communite with the ground while in orbit	1	3	3	Ensure comm. subsystem is structurally stable and validate stability with proper testing	None. The CubeSat is unoperational	RIT SPEX
2	**Comm. subsystem weight exceeds CubeSat weight limit**	Transceiver and/or antenna are bulky	CubeSat won't be accepted to NASA's launch program	1	3	3	Use lightest possible materials and/or purchase lightest equipment	Eliminate superfluous CubeSat capabilities	MSD team
3	**Lack of power supplied to comm. subsystem**	Comm. subsystem is inefficient or solar panels don't gather adequate power	CubeSat is unable to communite with the ground while in orbit	2	3	6	Collaborate with power acquisition team and only integrate essential comm. operations	Purchase a comm. system that consumes less power	MSD team & RIT SPEX
4	**Project is not completed within a single MSD cycle**	Inadequate time management, unexpected delays, and/or design challenges	Project is pushed to second MSD phase and CubeSat isn't completed in time to board NASA launch	2	1	2	Determine if the project is feasible within a single MSD cycle	Project is completed by a second MSD team or completed by RIT SPEX	RIT SPEX & DPL team
5	**Comm. subsystem encompasses too much volume**	Transceiver and/or antenna are bulky	CubeSat won't be accepted to NASA's launch program	1	3	3	Implement smallest design and/or purchase smallest equipment	Purchase a smaller comm. subsystem or eliminate superfluous equipment with CubeSat	MSD team & RIT SPEX
6	**Team members lack adequate knowledge about comm. systems**	Subject matter is not taught to students or students are unable to gather sufficient knowledge	Comm. subsystem doesn't function properly	2	3	6	Perform extensive background research and locate knowledgable faculty members	Project is completed by a second MSD team or completed by RIT SPEX	MSD team, DPL team, & RIT SPEX
7	**Team members lack adequate knowledge about other CubeSat requirements**	Previous MSD teams did not complete projects or do not supply sufficient details	Comm. subsystem is incompatible with CubeSat	2	3	6	Communicate with previous MSD teams	Redesign comm. subsystem to be compatible with CubeSat	MSD team
8	**Unable to obtain government license for communication**	Paperwork is not completed and/or insufficient testing	CubeSat won't be accepted to NASA's launch program	3	3	9	Conduct extensive background research and submit paperwork early	Revise proposal for license	MSD team
9	**Unable to obtain sufficient funds for the project**	Grant proposals are not accepted and equipment is too expensive	Comm. subsystem cannot be completed	3	3	9	Obtain funding prior to project	Project is completed by a second MSD team or by RIT SPEX	MSD team & RIT SPEX
10	**Comm. subsystem doesn't comply w/ government regulations**	Sufficient background reseach is not conducted	Communication license isn't granted	2	3	6	Conduct extensive background research	Redesign comm. subsystem or purchase alternative equipment	MSD team

Figure 9. *Table of risks associated with the described communication subsystem MSD project.*

CONSTRAINTS

- For a 1U CubeSat, the overall mass must be less than 1.33 kg. [3]
- For a 1.5U CubeSat, the overall mass must be less than 2.00 kg. [3]
- For a 2U CubeSat, the overall mass must be less than 2.66 kg. [3]
- For a 3U CubeSat, the overall mass must be less than 4.00 kg. [3]
- The outer dimensions of the CubeSat must be (10 × 10 × 10) cm. [3]
- The total internal stored chemical energy must be less than 100 Watt-hours. [3]
- The propulsion system must be compliance with AFSPCMAN 91-710 Volume 3. [1]
- The magnetic field outside of the CubeSat's static envelope must not exceed 0.5 Gauss above Earth's magnetic field. [3]
- The communication system must comply with FCC Part 25 rules, "Satellite communications." [9]
- The communication system must comply with FCC Part 5 rules, "Experimental radio service." [10]
- The communication system must comply with FCC Part 97 rules, "Amateur radio service." [11]
- If amateur radio communication is utilized, then AX.25 Protocol must be followed. [2]

PROJECT DELIVERABLES

The main project deliverable associated with this PRP is a functional and compatible communication system for a CubeSat, including a transceiver and an antenna. The student team members must determine the power and transmission requirements that the fully constructed CubeSat will require so that they can make appropriate decisions for the design and construction of an adequate communication subsystem.

BUDGET ESTIMATE

Four different combinations of potential design concepts were analyzed. The first two concepts strictly utilize commercial-off-the-shelf components, whereas the third and fourth budget concepts require the transceiver to be disassembled and altered, and they require the antenna to be designed and constructed from scratch. Thus, budget concepts three and four require a great deal of research, knowledge, and construction.

Budget concept (1)		
Component	**Reference**	**Price**
ISIS VHF downlink / UHF uplink transeiver	[5]	$9,500
Deployable antenna	[4]	$5,000
	Total	$14,500

Budget concept (3)		
Component	**Item(s) to purchase**	**Price**
Transeiver	Kenwood TH-D7	$500
Antenna	Aluminum, wire, steel	$50
	Total	$550

Budget concept (2)		
Component	**Reference**	**Price**
Microhard MHX-2400 transeiver	[7]	$700
Deployable antenna	[4]	$5,000
	Total	$5,700

Budget concept (4)		
Component	**Item(s) to purchase**	**Price**
Transeiver	Alinco DJ-C5	$150
Antenna	Aluminum, wire, steel	$50
	Total	$200

Figure 10. *Estimated budget required for different combinations of solutions.*

INTELLECTUAL PROPERTY CONSIDERATIONS

There are no anticipated intellectual property (IP) concerns associated with this specific project, i.e., the communication subsystem. However, there are likely IP concerns associated with the overall CubeSat design; specifically, IP considerations will likely be requested for the CubeSat's pay load which contains the new technology that the CubeSat is designed to test.

Other information

There appears to be a great amount of risk associated with this project as outlined in Figure 9. For example, prior to designing the communication subsystem, a vast deal of information needs to be known about the other subsystems of the CubeSat. Moreover, several proposals must be submitted and accepted in order for the communication subsystem to be approved by the FCC and compliant with all necessary government regulations.

Other research papers of interest

- Fanchini, G., & Gagliostro, D. (2011). The e-st@r CubeSat: Antennas system. *Acta Astronautica*, *69*(11), 1089-1095. doi:10.1016/j.actaastro.2011.06.009
- Garg, M., Sembera, J., & Franki, M. (2003). Satellite solutions CubeSat design team. *University of Texas at Austin*. Retrieved from http://courses.ae.utexas.edu/ase463q/design_pages/spring03/cubesat/web/Paper%20Sections/CubeSat%20Final%20Report.pdf
- Muri, P., Challa, O., & McNair, J. (2010). Enhancing small satellite communication through effective antenna system design. *The 2010 Communication Conference, Waveforms and Signal Processing Track*. Retrieved from IEEE. doi: 978-1-4244-8180-4/10/
- Noe, Chris. (2004). Design and implementation of the communications subsystem for the Cal Poly CP2 Cubesat project. *Computer Engineering Department, California Polytechnic State University:* San Luis Obispo.
- Ochoa, D., Hummer, K., & Ciffone, M. (2014). Deployable helical antenna for nana-satellites. *28th Annual AIAA/USU Conference on Small Satellites.* Retrieved from http://www.northropgrumman.com/BusinessVentures/AstroAerospace/Documents/pageDocs/tech_papers/SmallSat_DeployableHelical_ochoa_SSC14-IX-4.pdf

Project continuation information

It's expected that this project, i.e., developing a communication subsystem for a CubeSat, would be one of several projects contributing to the overall project of developing an entire CubeSat. Other PRPs are being drafted for vibration mitigation, structural fabrication, attitude control, the avionic subsystem, the thermal and radiation barrier, and power acquisition. The anticipated timeline for these projects is presented above in Figure 2. In addition to the topics covered in these PRPs, it's anticipated that significant research and testing will need to be completed beyond the scope of MSD; this will be completed by RIT SPEX. The purpose of additional testing and research is to meet several of the other criteria required for the overall goal of successfully launching a CubeSat. However, it's expected that the communication subsystem of the CubeSat can be completed in its entirety during a single year of MSD.

STUDENT STAFFING

Team member	Anticipated skills
ME 1	3D CAD Finite Element Analysis
ME 2	Basic machining Materials science
ME 3	Stress analysis Vibration analysis/mitigation
EE 1	Power consumption analysis Electromagnetic interference
EE 2	Basic circuit design and construction Board layout Soldering

Figure 11. *Table of project staffing and required skills for a MSD team to complete the design and construction of a CubeSat communication subsystem.*

Discipline	Quantity	General tasks
ME	3	Select appropriate type of antenna Design and contruct antenna Ensure antenna doesn't fail under launch conditions
EE	2	Select approprate type of antenna Assist constructing antenna Analyze power consumption of antenna Ensure antenna is compatible with transceiver
CE	N/A	N/A
IE	N/A	N/A
Other	N/A	N/A

Figure 12. *Table of the anticipated tasks that will be completed by students assigned to this project.*

REFERENCES

[1] Air Force Space Command Manual 97-710 Volume 3. *Range safety user requirements manual volume 3 – Launch vehicles, payloads, and ground support systems requirements.* July 1, 2004. Air Force Space Command. Electronic source.

[2] Beech, W. A., Nielson, D. E., & Taylor, J. Tucson Amateur Radio Corporation. *AX.25 link access protocol for amateur packet radio*. Version 2.2. July 1998. Electronic source.

[3] California Polytechnic State University. *CubeSat Design Specification*. Rev 13. 2009. San Luis Obispo, CA. Electronic source.

[4] Innovative Solutions in Space. Antenna systems. 2015. Web. Retrieved from http://cubesatshop.com/index.php?option=com_virtuemart&Itemid=70

[5] Innovative Solutions in Space. Communication systems. 2015. Web. Retrieved from http://cubesatshop.com/index.php?option=com_virtuemart&Itemid=67

[6] Klofas, B & Leveque, K. (2013). *A survey of CubeSat communication systems: 2009 - 2012*. SRI International. Electronic source. Retrieved from http://www.klofas.com/papers/

[7] Pumpkin Incorporated. *Pumpkin price list.* Rev 1. November 12, 2014. San Francisco, CA. Web. Retrieved from http://pumpkininc.com

[8] Selva, D. & Krejci, D. (2012). A survey and assessment of the capabilities of CubeSats for Earth observation. *Acta Astronautica,* 74. 50-68. doi:10.1016/j.actaastro.2011.12.014

[9] U.S Government Publishing Office. *Electronic code of federal regulations*. Title 47, Chapter 1, Subchapter B, Part 25. April 28, 2015. Web. Retrieved from http://www.ecfr.gov/cgi-bin/text-idx?SID=83c6b9ced4098ae62f4c2d3d10e05dfc&mc=true&node=pt47.2.25&rgn=div5

[10] U.S Government Publishing Office. *Electronic code of federal regulations*. Title 47, Chapter 1, Subchapter A, Part 5. April 28, 2015. Web. Retrieved from http://www.ecfr.gov/cgi-bin/text-idx?SID=7d23e341032a9472cdee137b99c35a47&mc=true&node=pt47.1.5&rgn=div5

[11] U.S Government Publishing Office. *Electronic code of federal regulations*. Title 47, Chapter 1, Subchapter D, Part 97. April 28, 2015. Web. Retrieved from http://www.ecfr.gov/cgi-bin/text-idx?SID=b073cd88472ac84b5632529d38a500ba&mc=true&node=pt47.5.97&rgn=div5

[12] PolySat. *CP1.* Web. Retrieved from http://polysat.calpoly.edu/launched-missions/cp1/

[13] Vidmar, Matjaz. (1992). *A homemade receiver for GPS & GLONASS satellites*. Web. Retrieved from http://lea.hamradio.si/~s53mv/navsats/analog.html

[14] Krallis, K. (2007). *137 MHz weather satellite reception antenna*. Web. Retrieved from http://en.wikipedia.org/wiki/Turnstile_antenna

[15] Astronautical Development, LLC. (2009). *Li-1 user manual,* (rev. 0.4). Web. Retrieved from www.astrodev.com

[16] Microhard Systems Inc. (2015). *MHX-2400 OEM industrial wireless modem.* Web. Retrieved from http://www.microhardcorp.com/MHX2420.php

[17] Universal Radio, Inc. (2012). *Amateur handheld transceivers.* Web. Retrieved from http://www.universal-radio.com/catalog/ht/0058.html

[18] eHam.net, LLC. (2013). *Kenwood TH-D7A dual band handi-talkie.* Web. Retrieved from http://www.eham.net/classifieds/detail/354128

[19] Stensat Group, LLC. *Products: Stensat radio beacon.* Web. Retrieved from http://www.stensat.org/products.html#products

OTHER RESOURCES ANTICIPATED

Category	Description	Resource Available?
Faculty	**Expertise in communication systems, preferably amateur radios**	☒
Environment	**No special accommodations expected**	☐
Equipment	**No special accommodations expected**	☐
Materials	**Aluminum, steel, & wire for antenna construction**	☒
Other	**N/A**	☐

PREPARED BY: Charles Krouse
DATE: May, 2015

APPENDIX A – SKILLS CHECKLIST

TENTATIVE PROJECT NAME: RIT SPEX: CubeSat communication subsystem
PROJECT CHECKLIST COMPLETED BY: Charles Krouse

For each discipline, the anticipated skills and/or knowledge that will be needed by students working on the aforementioned project are indicated. The skills are ranked in order of importance with 1 being the highest priority.

Mechanical Engineering: three students

1	3D CAD		Aerodynamics
	MATLAB programming		CFD
1	Machining (basic)		Biomaterials
2	Stress analysis (2D)	1	Vibrations
	Statics/dynamic analysis (2D)		Combustion engines
	Thermodynamics		GD&T (geometic dimensioning & tolerancing)
	Fluid dynamics (CV)		Linear controls
	LabView (data acquisition, etc.)	3	Materials science
	Statistics		DFM
			Robotics (motion control)
2	FEA		Composites
	Heat transfer		Other:
	Modeling of electromechanical & fluid systems		Other:
	Fatigue & static failure criteria (DME)		Other:
	Specifying machine elements		

Reviewed by (ME faculty): **N/A**

Industrial & Systems Engineering: zero students

	Statistical analysis of data – regression		Shop floor IE – methods, time study
	Materials science		Programming (C++)
	Materials processing – machining lab		
	Facilities planning – layout, material handling		DOE
	Production systems design – lean, process improvement		Systems design – product/process design
	Ergonomics – interface of people & equipment (procedures, training, maintenance)		Data analysis, data mining
	Math modeling – linear programming), simulation		Manufacturing engr.
	Project management		DFx -- Manuf., environment, sustainability
	Engineering economy – ROI		Other:
	Quality tools – SPC		Other:
	Production control – scheduling		Other:

Reviewed by (ISE faculty): **N/A**

Electrical Engineering: two students

2	Circuit design: AC/DC converters, regulators, amplifier ckts, analog filter design, FPGA Logic design, sensor bias/support circuitry		Digital filter design and implementation, DSP
1	Power systems: selection, analysis, power budget determination		Microcontroller selection/application
	System analysis: frequency analysis (Fourier, Laplace), stability, PID controllers, modulation schemes, VCO's & mixers, ADC selection		Wireless protocol, component selection
3	Circuit build, test, debug (scopes, DMM, function generators)		Antenna selection (simple design)
3	Board layout	1	Communication system front end design
	MATLAB		Algorithm design/simulation
	PSpice		Embedded software design/ implementation
	Programming: C, Assembly		Other:
4	Electromagnetics (shielding, interference)		Other:
			Other:

Reviewed by (EE faculty): **N/A**

Computer Engineering: zero students

	Digital design (including HDL and FPGA)		Wireless networks
	Software for microcontrollers (including Linux and Windows)		Robotics (guidance, navigation, vision, machine learning, and control)
	Device programming: Assembly language, C		Concurrent and embedded software
	Programming: Java, C++		Embedded and real-time systems
	Analog design		Digital image processing
	Networking and network protocols		Computer vision
	Scientific computing (including C and MATLAB)		Network security
	Signal processing		Other:
	Interfacing transducers and actuators to microcontrollers		Other:
			Other:

Reviewed by (CE faculty): **N/A**

Chemical Engineering: zero students

☐	Energy and material balances on chemical systems	☐	Electrochemistry
☐	Fluid dynamics and Heat transfer	☐	Inorganic chemistry
☐	Thermodynamics (traditional and chemical)	☐	Environmental science and sustainability
☐	Mass transfer and separation process design: distillation, multistage absorption and stripping, batch and fixed-bed adsorption, liquid-liquid extraction, crystallization, membrane separations.	☐	Advanced material science, polymer science
☐	Chemical reactor design: chemical kinetics, equilibrium, and catalysts.	☐	Surface tension and interfacial phenomena
☐	Engineering lab skills: rheology (in Newtonian and non-Newtonian systems), pressure, temperature, concentration. Pilot lab systems; delivery system assembly including pumps, valves and pressure sensors.	☐	
☐	MATLAB and EXCEL: solve complex chemical engineering mathematics problems	☐	
☐	Advanced chemistry knowledge: general, physical, and organic	☐	
☐	Micro- and nano-scale phenomena and process design	☐	
☐	Basic chemistry-based material science	☐	
☐	Basic engineering economics	☐	Other:
☐	Basic Process Control	☐	Other:
☐		☐	Other:

Reviewed by (Chem E faculty): **N/A**

APPENDIX B – 3 WEEK MSD PLAN

3 Week MSD project plan	
Week	**Tasks**
1	○ Receive PRP ○ Assign team member roles; e.g., team leader, lead engineer, facilitator, primary customer contact, purchasing lead ○ Speak with guide, read PRP, and gain a general understanding of the project ○ Conduct background research; e.g., understand CubeSat programs and research successful communication subsystems used by other CubeSats
2	○ Continue conducting background research; e.g., how will the other subsystems of the CubeSat interact, how does this affect communication, what are the regulations regarding communication, and can other communication systems be altered to satisfy needs ○ Speak with the customer / conduct stakeholder interviews as appropriate; e.g. RIT SPEX and FCC ○ Identify and reiterate the customer's requirements/expectations regarding the project
3	○ Assign specific tasks to team members; e.g., price antennas, price transceivers, design antenna, maintain contact with stakeholders, become acquainted with government regulations ○ Determine due dates for deliverables later in the semester ○ Begin conducting low-level research pertaining to individual roles; e.g. what specific antennas and transceivers are compatible with the CubeSat and how / can they be altered to be successfully integrated