Form Updated 17 October 2003

INTERNATIONAL AMATEUR RADIO UNION
AMATEUR SATELLITE FREQUENCY COORDINATION REQUEST

(Make a separate request for each space station to be operated in the amateur-satellite service.)

Administrative information:

[1] SPACECRAFT (published)	
[1a] name before launch	**ICEcube2**
[1b] proposed name after launch	**ICEcube2 (callsign N2VR)**
[1c] country of license	**USA**
[2] LICENSEE OF THE SPACE STATION (published)	
[2a] First name	Laurence
[2b] Last name	Hammer
[2c] Call sign	N2VR
[2d] Postal address	152 Olin Hall Ithaca, NY 14850
[2e] Telephone number	607 255-7883
[2f] Fax number	607 255-2287
[2g] Email address	ldh3@cornell.edu
[2h] Position in organisation	Director, Data Management, College of Engineering; Communications Advisor, ICEcube group; Advisor, W2CXM The Cornell Amateur Radio Club.
[3] ORGANISATIONS (published) -- Complete this section for EACH organisation	
[3a] Name of Organisation	Cornell University C/o Prof Mark Campbell
[3b] Physical Address	208 Upson Hall Ithaca, NY 14853 USA
[3c] Postal address	208 Upson Hall Ithaca, NY 14853 USA
[3d] Telephone Number	607 255-4268
[3e] Fax Number	607 255-1222
[3f] Email	mc288@cornell.edu
[3g] Website	http://www.mae.cornell.edu/Campbell/
[3h] Role of organisation in the project	Cornell Cubesat is a project of the School of Mechanical & Aerospace Engineering at Cornell University. The project is managed and directed by faculty and staff of

	project is managed and directed by faculty and staff of the University, and carried out by students of the University.
(3I) National Amateur Radio Society and address details	**American Radio Relay League [ARRL]** **Address:** 225 Main Street, Newington, CT 06111-1494 **Tel:** +1 (860) 594-0200 <HQ> **Fax:** +1 (860) 594-0259 <HQ>
(3J) National AMSAT Organisation and contact details	**AMSAT-NA** **850 Sligo Avenue, Suite 600** **Silver Spring, MD 20910** Telephone: +1 (301) 589-6062 Toll-free (U.S. only): 1-888-FBAMSAT (1-888-322-6728) Fax: +1 (301) 608-3410

Space station information:

[4] SPACE STATION (published)	
[4a] Mission(s) *Supply as much detail as possible about what the space station is expected to do. Use as much space as you need.*	This is satellite #1 of two identical satellites to fly this mission and will carry the callsign N2VR. Both will be launched on the same rocket in different payload carriers and be ejected into almost identical orbits. The purpose of the mission is to measure ionospheric scintillations in the upper atmosphere by flying a high-precision GPS receiver in low earth orbit and recording parameters from up to four GPS satellites simultaneously while passing through the solar terminators. The satellite will record the data received from the GPS satellites and download it to a ground station located on the Cornell campus using standard AX.25 packet radio protocol. For an introduction to Cornell's CubeSat project, see the web page at http://www.mae.cornell.edu/cubesat/newvisitor.html . The project has been named ICEcube, which stands for Ionospheric Scintillation Experiment. The ICEcube project is based on the design parameters of the CubeSat launch program developed by Dr. Robert Twigg of Stanford University, Palo Alto, CA. For more information on the CubeSat project concept and goals, see the document available at http://www.mae.cornell.edu/cubesat/commcubesat.pdf . The satellite is expected to have a useful life of between 6 and approximately 18 months. The satellite carries an onboard GPS and orbit propagator that will turn the radio system on only when the satellite is in view of Ithaca, NY USA. All communication must be initiated by the ground system and include the correct command password, and the satellite will not respond to communication requests that do not carry the recognized callsign, command and password sequence. The satellite will be powered off by the propagator if no

	communication request is received from the ground station, when the satellite does not have sufficient onboard power to complete a communications pass, and at the end of each communication pass as directed by the ground station.
[4b] Expected duration of each part of the mission.	The Command & Data Handling (C&DH) subsystem is the controller during the mission, running the orbit propagator and power regulation control algorithms. When the satellite passes through the area within 20 degrees of the equator, the GPS is turned on to collect position and signal strength information. A GPS data collection run lasts approximately 12 minutes. The data from the GPS is stored by C&DH until the satellite is in view of Ithaca NY USA, when it is downloaded by the ground station. The purpose of the mission is to gather as much information as possible about high atmospheric interference to GPS signals. The data will be analysed to see if a working hypothesis for the cause of ionospheric scintillation of GPS signals can be derived and possibly substantiated. These scintillations are strongest during the spring and fall months. Assuming an October 2004 launch we should see good data from the satellite very soon after launch, and we hope to continue collecting data through the spring 2005 months when scintillations should again be more pronounced.
[4c] Proposed transmit frequency plan *List each transmitting frequency with output power, bandwidth, emission type(s), and associated antenna pattern.*	The satellite will communicate with the ground station via packet radio using the AX.25 protocol on a single FM frequency on the 70cm band using an output power of 1 watt (FM simplex communication). The onboard antenna is a large patch design covering one side of the satellite, which is both actively and passively stabilized in flight to orient the satellite so there are constant “top” and “bottom” sides. The communications antenna occupies the bottom side of the satellite and has a 3dB beamwidth of approximately 60 degrees. One purpose of this document is to request assignment and coordination of this frequency from the IARU so this satellite does not intentionally interfere with any other satellite or service in view of Ithaca NY USA.
4[d] Proposed receive frequency plan. *List each receiving frequency, showing associated bandwidth, noise temperature, emission*	The satellite will communicate with the ground station via packet radio using the AX.25 protocol on a single FM frequency on the 70cm band (FM simplex communication). The onboard antenna is a large patch design covering one side of the satellite, which is both actively and passively stabilized in flight to orient the satellite so there are constant “top” and “bottom” sides. The communications antenna occupies the bottom side of the satellite and has a 3dB beamwidth of approximately 60 degrees. The ground station will communicate with the satellite through a helix antenna system of approximately 14 dB gain using 25 watts of transmit power. One purpose of this document is to request assignment and coordination of this frequency from the IARU so the ground

type(s), and antenna pattern.	transmissions do not intentionally interfere with any other satellite or service.
[4e] Physical Structure *General description including dimensions, mass, antennas and antenna placement, etc. Attach drawings.*	The ICEcube project is based on the design parameters of the CubeSat launch program developed by Dr. Robert Twigg of Stanford University, Palo Alto, CA. The basic CubeSat specification is for a 10x10x10cm cube-shaped package with a mass of no more than one kg, which is fitted into a launch carrier by Prof Twigg's group for launch. A CAD rendering of the outside of the satellite is included below as Appendix I. For CAD renderings of the individual parts and subsystems of the satellite, see http://www.mae.cornell.edu/cubesat/Structure_Pictures.html . The structure of this CubeSat is composed of a machined aluminum frame with aluminum sheet walls on five sides, with the sixth side (which faces earth during orbit) being a patch antenna for satellite-to-ground communication. A picture of the frame of the satellite is included below as Appendix II. The satellite is actively stabilized by magnetic coils, and passively stabilized by one gravity boom approx 1m in length which is unfurled approximately one hour after the satellite is deployed by the launch carrier. The satellite is stabilized such that the antenna is always facing the earth and the gravity gradient boom is toward the earth. The GPS receiver antenna is mounted on the "top side" of the satellite facing away from the earth, so it can receive signals coming from the GPS constellation already in high orbit around the earth.
[4f] Functional description *Describe each section's function within the satellite.*	Design documents detailing the various subsystems are available online at http://www.mae.cornell.edu/cubesat/ . While some documents are titled "Final Design," please note that these may be superceded as necessary once the final tests and assembly of the flight units is completed. Also please note that many of these are rather large documents, containing text, drawings and graphics, and may take a few minutes each to download even over a high speed Internet connection. The main payload of the satellite is a modified Cougar GPS receiver board, designed and built by Dr Paul Kintner's research group at Cornell University. The GPS receiver is turned on and off during the satellite's transit through the solar terminator and the data received is stored on the command and data handling board. When the satellite comes within sight of Ithaca, NY USA (lat 42 26 54 N, long 76 29 9 W), an automated ground station commands the satellite to download the received data and any telemetry detailing the onboard conditions and satellite status which the satellite has stored. Command & Data Handling consists of a small computer which contains the logic necessary to carry out the mission, and monitor and control the spacecraft's other systems. C&DH includes an orbit propagator which helps determine when the satellite needs to do a particular function, primarily when it is approaching a solar terminator (data collection zone) and when it is coming in visual

	range of Ithaca NY (communication zone). Attitude Determination & Control consists of a gravity gradient boom for passive stabilization and a set of torque coils for active stabilization. The gravity gradient boom is stowed for launch and deployed one hour after the satellite is ejected into space by the Cubesat carrier. The torque coils operate against the magnetic field of the earth to provide positive orientation and stabilization of the satellite during flight. The onboard radio system has an transmitter output power of 1W and operates on the 432 mhz band. The onboard antenna is a modified patch antenna design of –1 dB gain with a beamwidth of 70 degrees. The satellite will have solar cells on five sides. The design output of the solar cell charging system is 1.2 W on orbit average useable power from Emcore solar cells with 27.5% efficiency. Power storage capacity is via an array of three lithium-polymer (Li-Pol) batteries wired in series. Design documents as of June 2003 are available online at http://www.mae.cornell.edu/cubesat/2003/ spring%202003%20final%20spec/Power%20Final%20Design.doc
[4g] Power budget *Describe each power source, power consuming section, power storage, and overall power budget.*	The current power budget is attached as Appendix III. All power on the satellite are produced from high-efficiency solar cells. Power is stored in a bank of lithium-ion batteries and regulated by a power control subsystem. Other subsystems which use power are: - heating; there is a thermal heater which warms the batteries to keep them within their operating temperature specification - GPS, the science subsystem which monitors where the satellite is and gathers data on signal strength when passing through the scintillation zones - Attitude determination and control, which uses some power to power magnetorquing coils to orient the satellite - Command and data handling, which regulate the functions of the satellite and store science data - Communications, which receives signals from the ground station and downloads telemetry and data to the ground station

[5] TELECOMMAND (Will *NOT* published)	
[5a] Telecommand Frequency plan. *Provide <u>telecommand</u> frequencies, emission type(s), link budget, and a general description of any cipher system, etc.*	The satellite will communicate with the ground station via packet radio using the AX.25 protocol on a single FM frequency on the 70cm band using an output power of 1 watt (FM simplex communication). Telecommand will be carried out in a modal fashion, wherein the satellite will expect to receive commands to initiate transmission, download satellite condition telemetry and download science data collected during the mission. The satellite will not be programmed to initiate contact but rather to

	respond to communications received which contain the correct callsign, command and password sequence. The transmitter will be disabled by the Command & Data Handling subsystem when the satellite is not in view of Ithaca, NY USA so there is little chance that the satellite could be activated by unauthorized personnel.
[5b] Telecommand stations. *List call signs and locations of* <u>*telecommand*</u> *stations capable of turning off space stations transmitter(s) in case of interference.*	W2CXM 401 Barton Hall Ithaca, NY 14850 USA N2VR Ithaca, NY 14850 WB2EMS Danby, NY Note that the satellite carries an onboard orbit propagator that will turn the radio system on only when the satellite is in view of Ithaca, NY USA. All communication must be initiated by the ground stationand include the correct command passwords. The satellite will not respond to communication requests that do not carry recognized callsign, command and password sequences. The satellite will be powered off by the propagator if no communication request is received from the ground station, when the satellite does not have sufficient onboard power to complete a communications pass, and at the end of each communication pass as directed by the ground station.
[6] Telemetry (published)	
[7a] Telemetry Frequencies. *List all* <u>*telemetry*</u> *frequencies, emission bandwidth(s) type(s) and the link budget.*	The satellite will communicate with the ground station via packet radio using the AX.25 protocol on a single FM frequency on the 70cm band using an output power of 1 watt (FM simplex communication). Communication will be carried out in a modal fashion, wherein the satellite will expect to receive a specific commands to initiate download of satellite telemetry recorded during the mission. The satellite will not be programmed to initiate contact but rather to respond to communications received which contain the correct callsign, command and "password" sequence for each command.
[7b] Telemetry formats and equations. *Describe telemetry format including telemetry equations. (Final equations must be published as soon as available.)*	The Cougar GPS data format comprising the science portion of this mission is attached below as Appendix IV. The format of the internal communication packet between C&DH and Comm subsystems is attached below as Appendix V.

[7c] Is the format commonly used by radio amateurs? If not, please describe how and where will it be made available to them	The telemetry format is custom designed for this mission to best utilize the sensors, recording rates and link budget parameters defined and derived by the project team. The final telemetry format will be published on the project website at http://www.mae.cornell.edu/cubesat along with the rest of the project documents.
[7] Launch plans (published)	
[6a] Planned launch date.	Oct/Nov 2004
[6b] Launch agency	ISCK/YSDO Launch arrangements are being handled through the CubeSat group at Stanford University, Palo Alto CA.
[6c] Launch location	. Launch site is expected to be the rocket drome in BAJKONUR Kazakhstan, but this has not yet been confirmed.
[6d] Planned orbit *Include planned orbit apogee, perigee, inclination, and period.*	ISCK/YSDO answer: Current Orbit Parameters: Alt. 650-700 km, SSO, LTAN: 22:30

Earth station information:

[8] Typical uplink station (published)	
[8a] Describe a typical Earth station to transmit signals to the planned satellite.	25W transmitter operating through an 11 dB gain antenna on coordinated frequency. Transmitting station must transmit appropriate clearance codes to access satellite functions.
[8b] Link budget. *Show complete link budgets for all satellite functions.*	Link budget for ground-to-satellite attached as Appendix VI.
[9] Typical downlink station (published)	
[9a] Describe a typical Earth station to receive signals from the planned satellite.	11 dB gain helical or cross-polarized yagi antennas collecting signals. Receiver must have –136 dB noise floor or better to decode signals without a preamp. Received signals fed through TNC then decoded using AX.25 protocol. Results are either stored for processing (telemetry or data) or decoded and acted upon (satellite condition or command response codes).
[9b] Link budget. *Show complete link budgets for all satellite functions.*	Link budget for satellite-to-ground attached as Appendix VII.

Additional information:

[10] Please supply any additional information that may assist the Satellite Advisor in coordinating your request(s) *Use as much space as you need.*	The frequency for this mission should be coordinated with those of the other CubeSats flying on this same launch. The onboard communication system is designed for simplex operation in the 70cm US amateur band allocation, and we can set the frequency to any within that range.

[***] The licensee of the prospective space station has reviewed all relevant laws, rules, and regulations, and certifies that this request complies with all requirements to the best of his/her knowledge.

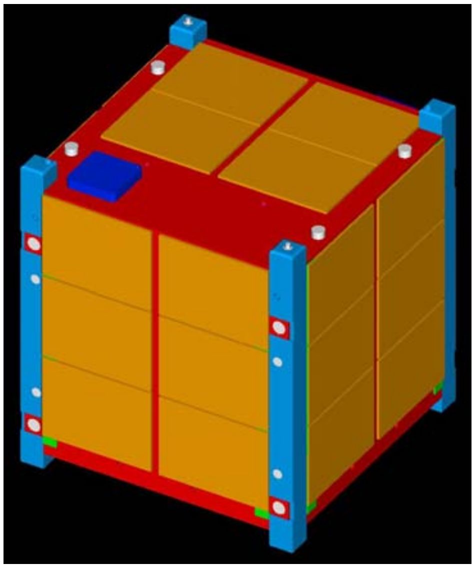
[ ] I disagree with IARU interpretations of Treaty requirements and ask the IARU Satellite Advisor to consider the following interpretation. Explanation follows.

* please tick appropriate box

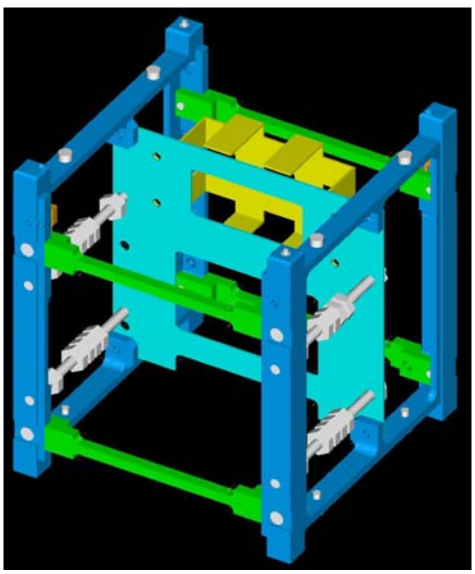
Signature: /s/ Laurence D. Hammer, N2VR

Date submitted: (this revised version) 28 Nov 2003

Appendix I. CAD drawing of the exterior of ICEcube satellite.



Appendix II. CAD rendition of frame of ICEcube satellite.



Appendix III. ICEcube Power Budget.

Orbit Information	
Time: 90 minutes	

Battery Information	
Battery Energy (Wh): 2.8	
Depth of Discharge: 35%	

Number of Batteries: 3

Solar Cell Information
Cell Orbital Average: .98 W

Sub-System Load Information

Subsystem	Current Draw (mA)	Supply Voltage (V)	Power (W)	Duty Cycle	Time (min)	Energy (J)
CnDH						
Tattetale Board (peak)	55	11.7	0.6435	100	90	0.96525
Tattetale Board (idle)	45	11.7	0.5265	0	0	0
Comm						
Transmit	843	3.3	2.7819	12	10.8	0.500742
Receive	68	3.3	0.2244	1	0.9	0.003366
Idle	15	3.3	0.0495	87	78.3	0.0645975
Total						0.5687055
GPS						
Board (in use)	395	5	1.975	25	22.5	0.740625
Board (low power)	0.32	5	0.0016	75	67.5	0.0018
Thermal						
Sensors	1.5	5	0.0075	1	0.9	0.0001125
Heaters	350	11.7	4.095	10	9	0.61425
ADCS						
Magnetometer	20	11.7	0.234		0	0
Torque Coils	1000	1.5	1.5		0	0
Power						
Microcontroller	10	5	0.05	100	90	0.075

Appendix IV. GPS data format (including internal GPS communication with C&DH).

Transmission direction	Flag	Sentence content
GPS ➔ C&DH	0	invalid Navigation solution.
GPS ➔ C&DH	1	2-D Navigation solution.
GPS ➔ C&DH	2	3-D Navigation solution.
GPS ➔ C&DH	3	SNR data

C&DH ➔ GPS 4 Propagator Input

C&DH ➔ GPS 5 Shut Down Warning

C&DH ➔ GPS 6 # of Satellites (SNR) to record

C&DH ➔ GPS 7 S4 mode (4 mins or 30 secs)

	Character / Representation			ASCII code		# of bytes
Prefix	☻			2		1
Flag	0			48		1
DATA	Invalid Nav Soln			N/A		34
Suffix	♥			3		1
Prefix	☻			2		1
Flag	1			49		1
DATA	2D Nav Soln			N/A		34
Suffix	♥			3		1
Prefix	☻			2		1
Flag	2			50		1
DATA	3D Nav Soln			N/A		34
Suffix	♥			3		1
Prefix	☻			2		1
Flag	3			51		1
SV #	N/A			SV# + 100		1
DATA	SNR			N/A		50
Suffix	♥			3		1
Prefix	☻			2		1
Flag	4			52		1
DATA	Propagator Input			N/A		48
Suffix	♥			3		1
Prefix	☻			2		1
Flag	5			53		1
DATA	NO DATA			N/A		0
Suffix	♥			3		1
Prefix	☻			2		1
Flag	6			54		1
DATA	# of Sats to record			48~57		1
Suffix	♥			3		1
Prefix	☻			2		1
Flag	7			55		1
DATA	S4 Mode			48 or 49		1

Suffix	♥			3		1

Appendix V. Internal communication packet between C&DH and Comm subsystems.

The only communication provisioned from CDH to comm. is data to be transmitted. The form of the data packet used is such:

D or T	E or C	# bytes	Data (1-256 bytes)	\r

D: The data is science data
T: The data is telemetry data
E: This packet is the end of the data set (# bytes = variable, 1 - 256)
C: This packet has more packets following it. (# bytes = 256)

We include a \r flag at the end of the packet to make sure that the expected last byte is correct.

Appendix VI. Link budget for ground-to-satellite.

CubeSat Communication Analysis 2.1

Uplink Budget

Pathloss	
Earth r	6378000
Altitude	600000
Pathloss	6.1158E+14

Downlink

	Value	Db	Variable
Transmiter power(dBW)	25	13.9794	Pt
Transmiter circuit loss	1	0	Lo
Transmitter antena gain(peak dBm)	11	10.41393	Gt
Terminal EIRP (dbW)	**37**	**24.39333**	EIRP
Path loss (dB)	6.1E+14	147.8645	Ls
Fade allowance (dB)		5	Lo
Other losses (dB)		5	Lo
Total path loss		157.8645	
Received Isotropic Power		**-133.471**	Pr
Receiver antenna gain		-1	Gr
Edge of coverage loss(dB)		2	Lo
Received signal power (dBW)		**-132.471**	Pr
Receiver noise figure at antenna port(dB)	7.5		memo
Receiver temperature(dB-K)	7	8.45098	

Receiver antenna temperature (dB-K)	7	8.45098	
System temperature (dB-K)	7	8.45098	
T° total		25.35294	
System G/T° (dB-K)		-26.3529	
Boltzmann Constant (dBW/K-Hz)		-228.6	
Noise spectral density (dBW/Hz)		-203.247	No=kT°
Received Pr/No (dB-Hz)		70.77587	(Pr/No)r
Data rate (dB-bits/s) 9600bps	**9600**	**39.82271**	**R**
Received Eb/No (dB)		30.95316	(Eb/No)r
Implementation loss		4	Lo
Required Eb/No (dB)(Pe=1E-5,FSK)		15	(Eb/No)req
Margin (dB)		**11.95316**	**M**

Appendix VII. Link budget for satellite-to-ground.

CubeSat Communication Analysis 2.1

Downlink Budget

Pathloss	
Earth r	6378000
Altitude	600000
Pathloss	6.1158E+14

Downlink

	Value	Db	Variable
Transmiter power(dBW)	1	0	Pt
Transmiter circuit loss	1	0	Lo
Transmitter antena gain(peak dBm)	1.25	0.9691	Gt
Terminal EIRP (dbW)	**3.25**	**0.9691**	EIRP
Path loss (dB)	6.1E+14	147.8645	Ls
Fade allowance (dB)		5	Lo
Other losses (dB)		5	Lo
Total path loss		157.8645	
Received Isotropic Power		**-156.895**	Pr
Receiver antenna gain		11	Gr
Edge of coverage loss(dB)		2	Lo
Received signal power (dBW)		**-143.895**	Pr
Receiver noise figure at antenna port(dB)	7.5		memo
Receiver temperature(dB-K)	5	6.9897	
Receiver antenna temperature (dB-K)	5	6.9897	
System temperature (dB-K)	5	6.9897	
T° total		20.9691	

System G/T° (dB-K)		-9.9691	
Boltzmann Constant (dBW/K-Hz)		-228.6	
Noise spectral density (dBW/Hz)		-207.631	No=kT°
Received Pr/No (dB-Hz)		63.73548	(Pr/No)r
Data rate (dB-bits/s) 9600bps	**9600**	**39.82271**	**R**
Received Eb/No (dB)		23.91277	(Eb/No)r
Implementation loss		4	Lo
Required Eb/No (dB)(Pe=1E-5,FSK)		15	(Eb/No)req
Margin (dB)		**4.912772**	**M**

Appendix VIII. Data budget for first six months of mission (Oct 2004 – April 2005)

Data Budget for CubeSat in 6 month period

Number of Passes	859	
Average Time/Pass (min)	8.62	
Communications Data Rate (bits/s)	9600	
Total bits (B3*B4*B5*60)	**4265038080**	
% of data lost due to link up time	39%	Found by (Total Access Time/Total Contact Time)
Total bits (B6*(1-B8))	**2608497290**	
% of packet used as overhead	7.84%	
Total bits(B9*(1-B11))	**2403991102**	total bits that can be downloaded in the 6 month period

Telemetry	**number**	**sample rate(Hz)**	**save rate(Hz)**	**bits/sample**	**duty cycle**	**Total Sampled bits**
Temperature Sensors(Main)	8	0.1	0.1	16	1	12.8
Temperature Sensors(Redundant)	8	0.1	0.1	16	1	12.8
Magnetometer (X,Y,Z coordinates)	3	0.1	0.5	16	1	4.8
Torque Coils (ADCS) Time Output	3	0.1	0.5	16	1	4.8
Power (Battery Voltage)	1	0.1	0.1	8	1	0.8
Power (String Current)	5	0.1	0.1	8	1	4
Orbit Propagator (Position Estimation - ECI)	3	0.1	0.1	16	1	4.8
Orbit Propagator (Velocity Estimation- ECI)	3	0.1	0.1	16	1	4.8
Science						
GPS X (ECEF)	1	0.1	0.1	24	0.1	0.24
GPS Y (ECEF)	1	0.1	0.1	24	0.1	0.24
GPS Z (ECEF)	1	0.1	0.1	24	0.1	0.24

GDOP	1	0.1	0.1	8	0.1	0.08
Hour	1	0.1	0.1	8	0.1	0.08
Min	1	0.1	0.1	8	0.1	0.08
Sec	1	0.1	0.1	8	0.1	0.08
SV#s (SNR data)	1	0.1	0.1	32	0.1	0.32
SV#s (Navigation Solution)	1	0.1	0.1	32	0.1	0.32
GPS (SNR)	2	50	50	8	0.1	80
				Total Save Rate(bps)		**131.28**
				Total bits in 6 months		**2041666560**
				Margin (B12 - B34)		**362324542.2**

Month	**Average Contact**	
October	0.0287	
November	0.0285	
December	0.0287	*** Values from Matlab
January	0.0292	
February	0.0286	
March	0.0281	
All 6 months	0.0286	