SCIntillation and IONosphere – eXtended (SCION-X) – A Small Satellite for Ionospheric and Atmospheric Science

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Abstract

SCION-X is a 12U CubeSat developed by National Central University that obtains more accurate observations on ionospheric space weather, atmospheric measurements for weather forecasting and air quality. The spacecraft is currently in the preliminary design phase and is expected to carry three science payloads, including the Cion-R GNSS Radio Occultation Receiver (GROR) with Reflectometry capability provided by GeoOptics, Compact Ionospheric Probe (CIP), and Hyper-SCAN.

The GROR for radio occultation analysis shall provide amplitude scintillation index and vertical profiles of electron density that is related to GNSS scintillation and positioning error. It shall also infer vertical distribution of dry temperature, and water vapor which are crucial to correctly modelling tropical cyclone intensity and precipitation. The Cion-R reflectometry receiver can also be used to derive properties of the Earth's surface, yielding information that includes sea surface roughness, soil moisture, and snow thickness. CIP conducts in-situ plasma measurements for F-region. It has a high Technological Readiness Level (TRL) and high sampling rates to measure ionospheric parameters and irregularities at sub-kilometer scales. These observations will help to correct and predict the positioning errors and satellite communications disruptions caused by ionospheric anomalies such as the generation and propagation of plasma bubbles. The third payload is Hyper-SCAN which is a newly developed hyperspectral imager for remote sensing of aerosol pollution over Taiwan. By analyzing the spectrum between 380 - 1020 nm and comparing with in-situ PM2.5 aerosol measurements on the ground from the Environmental Protection Administration, it is feasible to determine the relation between spectral optical depth measured by Hyper-SCAN and the corresponding aerosol sources. SCION-X is designed to provide measurements from the lower through the upper atmosphere that can be assimilated into weather forecast models after the launch in 2023.

Key word: ionosphere irregularity, weather forecast, radio occultation, air pollution (PM2.5)

1. Introduction

SCIntillation and IONosphere – eXtended (SCION-X) is the sixth spacecraft mission developed under the International Satellite Program in Research and Education (INSPIRE) consortium and the second spacecraft developed by National Central University (NCU). SCION-X, a 12 U CubeSat, has the ability to provide more accurate observations for atmospheric measurements and air quality from the lower atmosphere, as well as ionospheric plasma density for space weather monitoring and forecasts. Moreover, it demonstrates the capability of Taiwan universities to build a CubeSats platform for scientific missions.

2. Mission Objectives

The science mission objectives are dedicated to three aspects with three different payloads respectively: in-situ ionospheric science by using the Compact Ionospheric Probe (CIP), GNSS Radio Occultation (RO) observations for ionospheric profiles, scintillation, and weather forecasting, as well as GNSS Reflectometry (R) observations by using the GeoOptics Cion-R, and air pollution remote sensing instrument calibration by using Hyper-Spectral Camera ANalyzer (Hyper-SCAN). The objectives and science traceability matrix (STM) for the SCION-X mission are shown in Table 1.

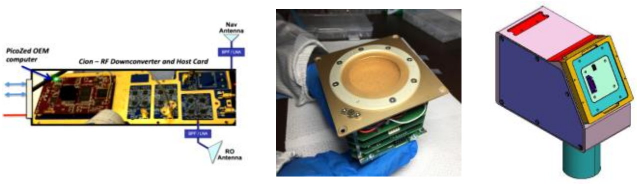
Table 1. Science Traceability Matrix.

Science Objectives	Measurement Requirements
Science-CIP	
S1. Provide in-situ measurements of ionospheric composition and plasma drift in the F region.	Ionospheric parameters in the F-region 20 km (100 km) horizontal sampling resolution
S2. Provide equatorial plasma bubbles and the associated vertical ion drifts measurements.	Latitude ≥ ±25° Observations for at least 12 months above 400 km
S3. Infer the electric fields driving horizontal plasma drift, and their relation to the F region wind dynamo.	Circular sun-synchronous orbit of 500 km with different ascending node from IDEASSat.
Science-GPS RO	
S4. Provide measurement of ionospheric vertical electron density profiles.	50 Hz for GPS L1, L2: • pseudorange • phase (Doppler residual velocity) • Cb/No (signal to noise)
S5. Provide regional measurements of low latitude ionosphere electron density.	GPS Almanac
S6. Measure regional scintillation in GNSS amplitude and phase for L1 and L2.	Spacecraft Precision Orbit Determination (POD) Latitude ≥ ± 25°
S7. Measure regional lower atmospheric temperature and water vapor.	
Science-GNSS Reflectometry	
S8. Perform an in-flight test of GNSS-R capability of Cion-R by pointing at a specified target.	Doppler shift, power, and delay between direct and reflected GNSS signal.
S9. Demonstrate the effect of data assimilation of water vapor and sea surface wind data on weather and PM2.5 forecasting.	Dry temperature and water vapor from GNSS-RO observations over the same region as the GNSS-R observations.
Science-Hyper-SCAN	
S10. Provide calibration spectra of PM2.5 aerosols that can be compared with in-situ source data from AERONET ground stations.	Spectrum from 380 – 1020 nm in daylight, not obscured by clouds with view angle of 30° or less. Measurement over NCU ground station. Coincident PM 2.5 source identification from ground.

The Cion-R GNSS RO / R receiver shown in Figure 1 (a) is under development by GeoOptics. Cion-R can provide vertical distribution of dry temperature and water vapor for the atmosphere, as well as amplitude scintillation index and vertical profiles of electron density for the ionosphere. The GNSS Reflectometry capability can be used to derive properties of the Earth's surface, including sea surface roughness which is proportionate to surface wind velocity, soil moisture, and snow thickness. By the assimilation of the observed information in atmospheric weather forecast models, it enhances the prediction accuracy for cyclogenesis, precipitation, and PM2.5 aerosols over Taiwan and the Southeast Asian region.

CIP shown in Figure 1 (b) is an in-situ plasma sensor with high Technological Readiness Level (TRL) and high sampling rates and developed by NCU Space Payload Laboratory. It is an all in one sensor combining Retarding Potential Analyzer, Ion Trap, Ion Drift Meter, and Planar Langmuir Probe modes in a time sharing manner to provide ionospheric parameters and structures at a high temporal resolution, and further infer the structure of anomalous phenomena like plasma bubbles.

Hyper-SCAN shown in Figure 1 (c) is a hyperspectral imager and under development by the NCU Space Optics Laboratory. By analyzing the spectrum between the wavelength of 380 – 1020 nm, it will conduct air pollution remote sensing and measure spectral signatures that can be used to identify composition of air pollutants near AERONET in-situ monitoring stations for instrument calibration and qualification.



(a) (b) (c)

Figure 1. Payloads in SCION-X mission: (a) Cion-R; (b) CIP; (c) Hyper-SCAN.

3. Concept of Operation

For orbit requirement drivers, the considerations for designing the orbit of SCION-X include launch opportunities and finances, mission lifetime, and payload operations including communication time and observation time. For Hyper-SCAN, the lower the orbital altitude, the higher the resolution and sensor performance, while for Cion-R, the higher the orbital altitude, the larger the vertical profile that can be measured. There are two circular orbits considered, with orbital elements summarized in Table 2. One option is a 500 km circular sun-synchronous orbit (CirSSO) that is same as the FORMOSAT 7-R Triton (FS7-R) satellite, which will measure wind fields in the meridional direction due to its high inclination. Another circular orbit is also examined: a 500 km circular orbit with an inclination of 25° (Cir_i25) that has the capability to measure the wind field in the zonal direction. Moreover, the low inclination will be useful for the CIP science mission to measure low latitude plasma irregularities. The one-day ground track of the two orbits simulated with STK are shown in Figure 2, where the CirSSO is represented in cyan while the Cir_i25 is in yellow.

Table 2. Orbital elements of the two candidate orbits.

	CirSSO	Cir_i25
LTDN	10:00 - 14:00	-
Altitude	500 km	
Inclination	97.41°	25°
RAAN	279.26°	
Argument of periapsis	0°	
True anomaly	0°	

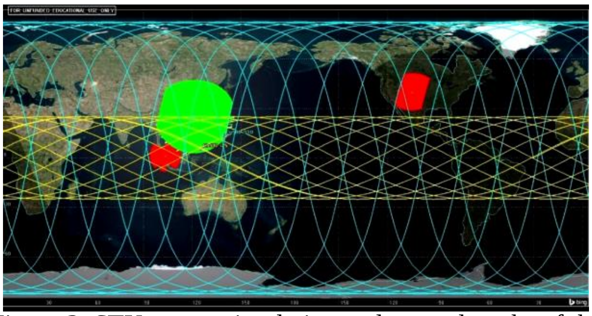


Figure 2. STK access simulation and ground tracks of the two candidate orbits.

Table 3 defines the operation modes of SCION-X mission. The concept of operation modes are mainly divided into Emergency Mode and Nominal Mode. Emergency Mode (Phoenix and Safe) is to recharge battery with low power consumption, while Nominal Mode is to charge battery with a higher pointing accuracy (Charging), conduct communication (TT&C), and perform the science missions (Science) with the carried payloads. When the spacecraft is within line of sight of the ground station, the X-band / S-band transmitter shall be turned on to downlink science data to the ground station in TT&C mode. In addition, Hyper-SCAN will be also operated in TT&C Mode with the sensor pointing towards NCU ground stations during daytime. In Science Mode, CIP and Cion-R shall be activated during eclipse and shall be turned off during the day side due to ionospheric plasma bubbles that occur on the night side of Earth in low latitudes.

Table 3. Operation modes of SCION-X.

	EMERGENCY		NOMINAL			
	Phoenix	Safe	Charging	TT&C	Science - GROR	Science – CIP
CDH	ON	ON	ON	ON	ON	ON
EPS	ON	ON	ON	ON	ON	ON
ADCS	OFF	Coarse Sun Point	Fine Sun Pointing	Surface pointing	LVLH	LVLH
UHF Tx	Beacon	Beacon	Beacon	Beacon	Beacon	Beacon
UHF Rx	ON	ON	ON	ON	ON	ON
X-Band / S-Band	OFF	OFF	OFF	ON	OFF	OFF
GROR	OFF	OFF	OFF	OFF	As required	As required
CIP	OFF	OFF	OFF	OFF	As required	As required
Hyper-SCAN	OFF	OFF	OFF	OFF (Night) ON (Sunlight)	OFF	OFF

The transition between the modes is based on the battery state of charge (SOC) and the lighting state. Figure 3 indicates the flow chart of the operation mode transition. Currently, the critical values of SOC are based on the experiences of IDEASSat (INSPIRESat-2).

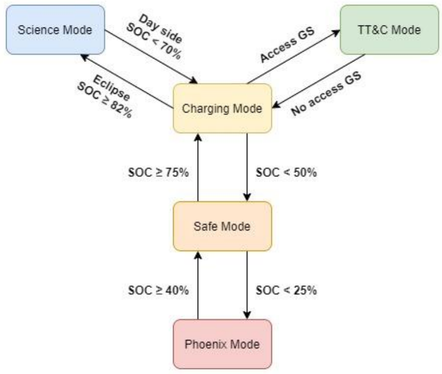
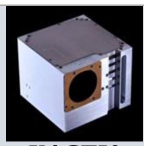


Figure 3. Flow chart of operation mode transition.

4. System Definition

The requirements of Attitude Determination and Control Subsystem (ADCS) of SCION-X are capable of providing 3-axis attitude control, and Sun pointing, surface pointing, and LVLH pointing. Moreover, it shall provide a maximum angular acceleration of 0.03° s^{-2} and maintain ± 0.5° (3-σ) pointing accuracy. There are two considered ADCS options: XACT50 from Blue Canyon Technologies and CubeADCS from CubeSpace with specifications shown in Table 4. XACT50 is an integrated ADCS with a relative high price, however, its control and operations have heritage from IDEASSat developed by NCU, which also used XACT15 from the XACT series. Compare to XACT50, CubeADCS has a lower price but is more complex to assemble due to all its external components listed in Table 4.

Table 4.Specifications of XACT50 and CubeADCS.

	 **XACT50**	 **CubeADCS**
Pointing accuracy	3 axes: ±0.007°	3 axes: ±0.2°
Mass	1.23 kg	0.85 kg
Volume	0.75U	0.64U
Electronics input voltage	12V	3.3V, 5V
Momentum	50 mNms	30 mNms
Components	Reaction wheels, magnetorquer, magnetometer, CSS, IMU, GPS, Star Tracker	Reaction wheels, magnetorquer, magnetometer, CSS, IMU, Star Tracker

The Communication (COMM) subsystem shall downlink science data from the spacecraft via X-band or S-band due to its high data rate, as well as tracking and telemetry beacon signals and command uplink from the ground station via UHF amateur radio bands. The active ground stations for using S-band to downlink are National Central University (NCU), University of Colorado at Boulder (CU) in the US, and Nanyang Technological University (NTU) in Singapore. Only the NCU ground station is available for X-band. The experience from IDEASSat can be applied to implementing S-band communications. However, a much higher data rate is available if X-band communications are used. The NCU ground station is the main station that receives the science data and uplinks commands. STK simulation is used to calculate the average access time within a year for the CirSSO and Cir_i25.

The preliminary data volume estimate is calculated for the three payloads aboard SCION-X. CIP will produce 2240 bytes of data per measurement point in its Fast mode during the entire eclipse period (TBD). GROR (Cion-R) generates data with the data rate of 37000 bytes / sec, 50 Hz sampling rate for RO and 1 Hz for Precision Orbit Determination (POD). GROR is functional during eclipse, but with duty cycle limited by power. Thus, the duty cycle of CIP and GROR will be actually determined based on the trade off between data size and power limitations, as well as the requirements from the payload teams. There are 20 Mbytes from Hyper-SCAN imaging for 5 seconds, which is only turned on when accessing Taiwan and during daylight times. The aerosol mission requires two good observations per season.

Table 5. One-year data size summary.

	CirSSO		Cir_i25	
	X-band	S-band	X-band	S-band
CIP (GB)	26.64	26.64	24.90	24.90
GROR (GB)	272.00	253.53	342.74	342.74
Hyper-SCAN (GB)	7.51	7.51	8.24	8.24
Total Science Data (GB)	306.14	287.67	375.89	375.89
Downlink (GB)	47.34	3.49	296.04	10.63
Margin (GB)	-258.81	-284.18	-79.85	-365.26

The Electrical Power Subsystem (EPS) shall be able to store electrical power, distribute power to all subsystems and payloads, protect the battery from overcharging and over discharging. Table 6 to Table 9 shows the power budget in Science Mode by using S-band / X-band communication and XACT50 / CubeADCS for ADCS for the worst case. For the 4 cases, the remaining power margins are positive and still have approximately 30% margin by using 40 cells Azurspace solar cells.

Table 6. Power budget in Science Mode by using S-Band downlink and XACT50 for ADCS.

	CirSSO		Cir_i25	
	Duty Cycle	Peak (W)	Duty Cycle	Peak (W)
Heater	25.00%	1.53	25.00%	1.53
EPS	100.00%	3	100.00%	3
XACT50	100.00%	7.59	100.00%	7.59
Cion-R	23.33%	3.50	31.54%	4.73
POD	0.00%	0	0.00%	0
Antenna	23.33%	0.12	31.54%	0.16
CDH	100.00%	1.4	100.00%	1.4
UHF (Tx)	6.37%	0.13	6.37%	0.13
UHF (Rx)	93.63%	0.14	93.63%	0.14
S-Band (Tx)	10.57%	0.53	5.30%	0.27
Hyper-SCAN	0.50%	0.03	0.50%	0.03
CIP	40.49%	1.94	37.85%	1.82
Total	-	19.90	-	20.78
Solar Panels	59.51%	25.87	62.15%	27.02
Margin	-	30.00%	-	30.00%

Table 7. Power budget in Science Mode by using X-Band downlink and XACT50 for ADCS.

	CirSSO		Cir_i25	
	Duty Cycle	Peak (W)	Duty Cycle	Peak (W)
Heater	25.00%	1.53	25.00%	1.53
EPS	100.00%	3	100.00%	3
XACT50	100.00%	7.59	100.00%	7.59
Cion-R	25.03%	3.75	31.54%	4.73
POD	0.00%	0	0.00%	0
Antenna	25.03%	0.12	31.54%	0.16
CDH	100.00%	1.4	100.00%	1.4
UHF (Tx)	6.37%	0.13	6.37%	0.13
UHF (Rx)	93.63%	0.14	93.63%	0.14
X-Band (Tx)	5.29%	0.63	5.30%	0.64
Hyper-SCAN	0.50%	0.03	0.50%	0.03
CIP	40.49%	1.94	37.85%	1.82
Total	-	20.27	-	21.15
Solar Panels	59.51%	25.87	62.15%	27.02
Margin	-	27.63%	-	27.72%

Table 8. Power budget in Science Mode by using S-Band downlink and CubeADCS for ADCS.

	CirSSO		Cir_i25	
	Duty Cycle	Peak (W)	Duty Cycle	Peak (W)
Heater	25.00%	1.53	25.00%	1.53
EPS	100.00%	3	100.00%	3
CubeADCS	100.00%	6.58	100.00%	6.58
Cion-R	21.49%	3.22	29.70%	4.46
POD	100.00%	0	100.00%	0
Antenna	21.49%	0.11	29.70%	0.15
CDH	100.00%	1.4	100.00%	1.4
UHF (Tx)	6.37%	0.13	6.37%	0.13
UHF (Rx)	93.63%	0.14	93.63%	0.14
S-Band (Tx)	10.57%	0.53	5.30%	0.27
Hyper-SCAN	0.50%	0.03	0.50%	0.03
CIP	40.49%	1.94	37.85%	1.82
Total	-	18.60	-	19.48
Solar Panels	59.51%	25.87	62.15%	27.02
Margin	-	39.08%	-	38.68%

Table 9. Power budget in Science Mode by using X-Band downlink and CubeADCS for ADCS.

	CirSSO		Cir_i25	
	Duty Cycle	Peak (W)	Duty Cycle	Peak (W)
Heater	25.00%	1.53	25.00%	1.53
EPS	100.00%	3	100.00%	3
CubeADCS	100.00%	6.58	100.00%	6.58
Cion-R	23.19%	3.48	29.70%	4.46
POD	100.00%	0	100.00%	0
Antenna	23.19%	0.11	29.70%	0.15
CDH	100.00%	1.4	100.00%	1.4
UHF (Tx)	6.37%	0.13	6.37%	0.13
UHF (Rx)	93.63%	0.14	93.63%	0.14
S-Band (Tx)	5.29%	0.63	5.30%	0.64
Hyper-SCAN	0.50%	0.023	0.50%	0.03
CIP	40.49%	1.94	37.85%	1.82
Total	-	18.97	-	19.85
Solar Panels	59.51%	25.87	62.15%	27.02
Margin	-	36.38%	-	36.08%

The NCR18650B-H00BA Lithium-ion battery cells with the energy density of 3,250mAh are considered to be used aboard SCION-X. For performance requirements, a considered load efficiency of 80%, and the maximum Depth of Discharge (DOD) of 50%, the required minimum battery capacity and total battery cells required are shown in Table 10. In each case, the minimum total number of batteries required for SCION-X is 8.

Table 10. Battery sizing for SCION-X mission.

		CubeADCS		XACT50		Unit
		CirSSO	Cir_i25	CirSSO	Cir_i25	
S-band	**Minimum battery capacity**	2.68	2.61	2.87	2.79	Ahr
	Serial	4	4	4	4	#
	Parallel	2	2	2	2	#
	Total battery number	8	8	8	8	#
X-band	**Minimum battery capacity**	2.73	2.66	2.92	2.84	Ahr
	Serial	4	4	4	4	#
	Parallel	2	2	2	2	#
	Total battery number	8	8	8	8	#

The Command and Data Handling (C&DH) board shall be capable of data interfacing with the other spacecraft subsystems, as well as the storage of science and housekeeping data. The MicroSemi SmartFision2 System on Module (SOM) is considered to be used as C&DH board for SCION-X, which is same as IDEASSat, while the ISOS flight software developed by the ARCADE (INSPIRESat-4) team is also considered.

For the SCION-X structure, the pointing requirements of internal spacecraft components are indicated in Table 11. Note that the scientific payload placements have a higher priority. The spacecraft center of gravity shall be located within a radius of 20 mm from its geometric center. There are two considered concepts of SCION-X structure. For the case 1 shown in Figure 4, it has the center gravity offset of 15.36 mm from the geometric center, while 17.72 mm in the case 2 shown in Figure 5. Case 1 is the optimal case due to the margins for center gravity, and in Case 2 the Cion-R antenna occupies whole anti-ram face, optimizing antenna gain. Further considerations will be determined by thermal analysis.

Table 11. Pointing requirements and preferred placements of SCON-X subsystems.

GROR	Ram /Anti-ram	**EPS**	Thermally insulated
CIP	Ram	**Battery**	Near EPS
Hyper-SCAN	Nadir	**CDH**	Center to minimize cable length
UHF Transceiver	Ram/Anti-ram, not hindered by solar panels	**ADCS**	Geometric center (Reaction wheels)
X / S-band Transmitter	Near X / S-band antenna	**POD antenna**	Zenith
X / S-band antenna	Nadir	**Cion-R antenna**	Ram / Anti-ram

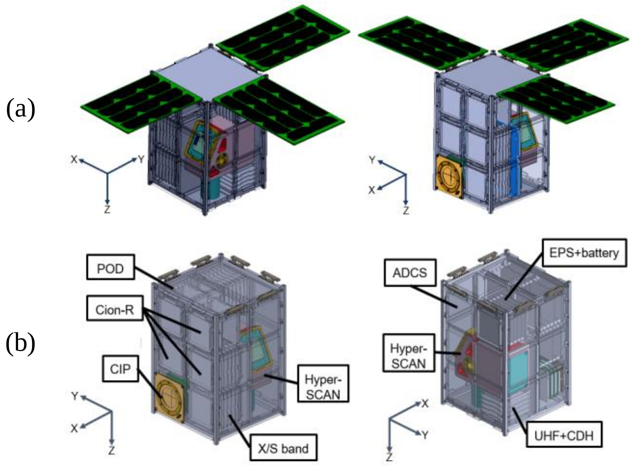


Figure 4. SCION-X structure concept for case 1 with (a) deployable solar panels; (b) internal components.

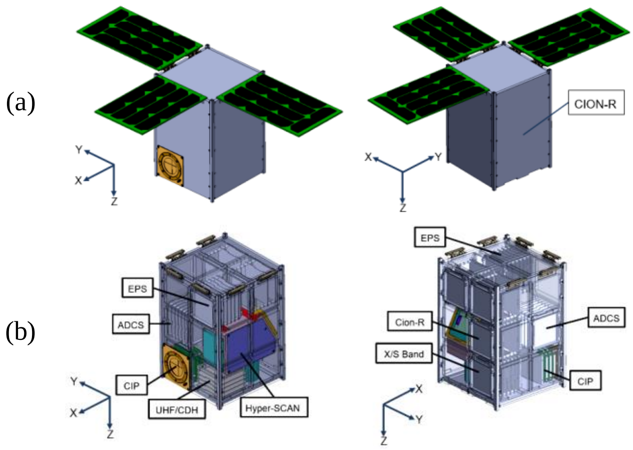


Figure 5. SCION-X structure concept for case 2 with (a) deployable solar panels; (b) internal components.

The Thermal Control Subsystem (TCS) shall maintain the subsystems within the operational temperature range summarized in Table 12 at all times, even in the worst hot case (the spacecraft in fully sunlit space) and worst cold case (the spacecraft is in eclipse).

Table 12. Operational temperature range of SCION-X components.

GROR (Cion-R)	-40° to +85°	**Battery pack**	0° to +40°
GROR Antenna (TW3872E)	-40° to +85°	**C&DH**	-25° to +65°
UHF (EnduroSat)	-35° to +80°	**ADCS (XACT50)**	-10° to +70°
X-band (EnduroSat)	-30° to +70°	**ADCS (CubeADCS)**	-10° to +60°
S-band (CPUT)	-25° to +61°	**CIP**	-10° to +50°

5. Conclusions

The SCION-X mission is in the preliminary design stage currently, and will be entering the Critical Design stage in February 2021, upon which the team will decide on the exact components to use. Additionally, it is expected to conduct global low-latency GNSS radio occultation sounding of the atmosphere and ionosphere, reflectometry measurements of sea surface winds, and to assess the aerosol pollution environment over Taiwan after being launched in 2023.

6. Acknowledgement

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7. References

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