FORMOSAT-7/COSMIC-2
Progress Update and its Launch Plan

Nick L. Yen

04-20-2015
IROWG-4 Melbourne, 16~22 April 2015
Brief History of FORMOSAT-3 / COSMIC-1 Mission
FORMOSAT-3 / COSMIC - Minotaur Launch Success

Launch Date: April 15, 2006 at UTC 01:40
Launch Site: Vandenberg AFB, CA, U.S.A.

Initial Orbit: Altitude ~515 km; Inclination ~72°
Final Orbit: Altitude ~800 km; Inclination ~72°

FORMOST-3 / COSMIC
Total Cost: ~ U.S. $ 100 M
- the first Radio Occultation Constellation that demonstrates the value of GPSRO in Weather, Climate and Space Weather -
GPSRO has Significant Impact:
Ranked #5 among all observing systems in reducing forecast errors, despite the small number of soundings.

Forecast error contribution (%)

Published in the Quarterly Journal of the Royal Meteorological Society

Courtesy: Carla Cardinali and Sean Healy
ECMWF, 22 October, 2009

AMSU-A: Adv MW Sounder A on Aqua and NOAA POES (T)
IASI: IR Atmos Interferometer on METOP (T,H)
AIRS: Atmos IR Sounder on Aqua (T,H)
AIREP: Aircraft T, H, and winds
GPSRO: RO bending angles from COSMIC, METOP
TEMP: Radiosonde T, H, and winds
QuikSCAT: sfc winds over oceans
SYNOP: Sfc P over land and oceans,H, and winds over oceans
AMSU-B: Adv MW Sounder B on NOAA POES
GOES winds
METEOSAT winds
Ocean buoys (Sfc P, H and winds)
PILOT: Pilot balloons and wind profilers (winds)
HIRS: High-Resol IR Sounder on NOAA POES (T,H)
MSG: METEOSAT 2nd Generation IR rad (T,H)
MHS: MW humidity sounder on NOAA POES and METOP (H)
AMSRE: MW imager radiances (clouds and precip)
SSMI: Special Sensor MW Imager (H and sfc winds)
GMS: Japanese geostationary satellite winds
MODIS: Moderate Resolution Imaging Spectroradiometer (winds)
GOES IR rad (T,H)
MTSATIMG: Japanese geostationary sat vis and IR imagery
METEOSAT IR Rad (T,H)
O3: Ozone from satellites
GPSRO Ranked #3 among other NOAA Instruments in Impact per Observation

Adjoint-based estimate of 24-hr global forecast error reduction in wind, temperature and surface pressure combined as energy (J/kg)

From Ron Gelaro, NASA, GMAO
FORMOSAT-3 / COSMIC Appears on Major Global Publications

International famous periodicals are争相報導福三衛星星系

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FORMOSAT-3/COSMIC RO Accumulated Atmospheric Profiles

Processed data for cosmic: 2006.111-2015.102
Total atmospheric occultations: 5,961,187

Occultations per day

Date


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Courtesy of UCAR CDAAC
FORMOSAT-3/COSMIC RO Accumulated Ionospheric Profiles

Processed data for cosmic: 2006.111-2015.102
Total ionospheric occultations: 4,088,040

IROWG-4 Melbourne, 16~22 April 2015

Courtesy of UCAR CDAAC
<table>
<thead>
<tr>
<th>Country</th>
<th>Users</th>
<th>Total</th>
<th>Country</th>
<th>Users</th>
<th>Total</th>
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<tbody>
<tr>
<td>U.S.A.</td>
<td>751</td>
<td>33</td>
<td>Finland</td>
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<td>447</td>
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<td>China</td>
<td>261</td>
<td>19</td>
<td>Egypt</td>
<td>7</td>
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<td>78</td>
<td>18</td>
<td>Nepal</td>
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<td>U.K.</td>
<td>55</td>
<td>18</td>
<td>Senegal</td>
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<td>Germany</td>
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<td>16</td>
<td>U.A.E.</td>
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<td>Russia</td>
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<td>13</td>
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<tr>
<td>Canada</td>
<td>47</td>
<td>13</td>
<td>Ireland</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Korea</td>
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<td>12</td>
<td>U.S.A.</td>
<td>2</td>
<td>1</td>
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<tr>
<td>Australia</td>
<td>41</td>
<td>10</td>
<td>Jamaica</td>
<td>1</td>
<td></td>
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<tr>
<td>Brazil</td>
<td>39</td>
<td>10</td>
<td>Macedonia</td>
<td>1</td>
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<tr>
<td>France</td>
<td>37</td>
<td>9</td>
<td>Uganda</td>
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<td>Indonesia</td>
<td>37</td>
<td>8</td>
<td>Kenya</td>
<td>3</td>
<td></td>
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<td>Italy</td>
<td>37</td>
<td>7</td>
<td>Cameroon</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Global Data Users Status: 74 countries; 2693 users**

*As-of 03/31/2015*
“The Most Accurate and Stable Thermometer in Space”

was first used by Rick Anthes in the opening remarks of

Emeritus UCAR President

FORMOSAT-3/COSMIC Workshop 2006  < Early Results and IOP Campaigns >

Taipei, November 28 – December 1, 2006
Formation of FORMOSAT-7 / COSMIC-2 Mission
Advocacy of FORMOSAT-7/COSMIC-2 Mission

- The launch and the constellation deployment of the FORMOSAT-3/COSMIC-1 satellites and providing the RO profiles to the global user community, the usefulness and effectiveness of the RO data have been widely demonstrated and verified.

- The FORMOSAT-3/COSMIC-1 was originally designated as a 2-year experimental mission. Soon after the FORMOSAT-3/COSMIC-1 Workshop 2006 < Early Results & IOP Campaigns >, the advocacy for its follow-on mission began.

- Thanks to the following key individuals to promote/advocate the follow-on mission and incubate the establishment of the FORMOSAT-7/COSMIC-2 Mission:
  - UCAR: Rick Anthes, Jeff Reaves, Jack Fellows, Bill Kuo, Bill Schreiner, Dave Ector
  - NSF: Jay Fein, Eric DeWeaver
  - NOAA: Mary Kicza, Gary Davis, Mike Crison (deceased), Pete Wilczynski
  - JPL: Tony Mannucci
  - Taiwan: L-C Lee, C-H Liu, C-Y Tsay, G-S Chang, J.J. Miau, C-Y Huang, Tiger Liu
  - Many others not mentioned above

- A Taiwan-U.S. official TECRO / AIT collaboration agreement was signed in May 2010 for the execution of the FORMOSAT-7 / COSMIC-2 Joint Mission.
FORMOSAT-7/COSMIC-2 Agreement Implementation

MOST: Ministry of Science and Technology
NARL: National Applied Research Lab
NSPO: National Space Organization
TECRO: Taipei Economic and Cultural Representative Office
AIT: American Institute in Taiwan
DOC: Department of Commerce
NOAA: National Oceanic and Atmospheric Administration
FORMOSAT-7/COSMIC-2 Joint Program WBS

- **Joint Program**
- **WBS 1.0 Program Management**
  - Advisory & Supervision
  - Joint Program Management
  - NSPO Program Management
  - NOAA Program Management
- **WBS 2.0 System Engineering**
  - System Analysis
  - System & Interface
- **WBS 3.0 Mission Assurance**
  - NSPO Mission Assurance
  - NOAA Mission Assurance
- **WBS 4.0 Satellite Development**
  - SL for Launch #1
  - SL for Launch #2
- **WBS 5.0 Launch**
  - Launch #1
  - Launch #2
  - Frequency Coordination
  - Mission Operations
  - Ground System
  - US DPC
  - Taiwan DPC
  - DPC IF
  - US RO Data Utilization
  - Taiwan RO Data Utilization
  - US Science Data Application
  - Taiwan Science Data Application
- **WBS 6.0 Ground & Mission Operations**
  - Responsible by Both Side
  - Responsible by NSPO
  - Responsible by NOAA
- **WBS 7.0 Data Processing**
  - Responsible by Both Side
  - Responsible by NSPO
  - Responsible by NOAA
- **WBS 8.0 Data Utilization**
  - Responsible by Both Side
  - Responsible by NSPO
  - Responsible by NOAA

**Abbreviations:**
- SL: Satellite
- PL: Payload
- MSD: Multi-Satellite Dispenser
- AIT: Assembly, Integration, and Test
- DPC: Data Processing Center
- IF: Interface
- RO: Radio Occultation
FORMOSAT-7/COSMIC-2 Constellation

“Transition from Research to Operation”

➢ **1st Launch**
  - 6 SC to a parking orbit with inclination angle of 24~28.5 deg.
  - Through constellation deployment, 6 SC will be separated to 6 orbital planes with 30-deg separation.

➢ **2nd Launch**
  - 6 SC to a parking orbit with inclination angle of 72 or 108 deg.
  - Through constellation deployment, 6 SC will be separated to 6 orbital planes with 30-deg separation.
  - NSPO-built satellite will be sent to the space by the 2nd launch (optional).

**Total Estimate Budget:** ~ U.S. $ 463 M
(Rick Anthes estimated @ U.S. $ 420 M)
RO Data Distribution after the 1st Launch

5770 raw radio occultation profiles by 6 SC, the data distribution is within a band of ± 50 deg latitude.
Total RO Data Distribution after the 1\textsuperscript{st} and the 2\textsuperscript{nd} Launch

11958 raw radio occultation profiles by 6 SC from the 1\textsuperscript{st} launch (yellow dots) and 6 SC from the 2\textsuperscript{nd} launch (red dots).

IROWG-4 Melbourne, 16\textsuperscript{th}-22 April 2015
Greater FORMOSAT-7 v.s. FORMOSAT-3 Global GPSRO Coverage

FORMOSAT-3 Occultation – 3 Hrs Coverage

FORMOSAT-7 Occultation – 3 Hrs Coverage
FORMOSAT-7 / COSMIC-2 Mission Requirement
## RO Data Products and Data Requirement

<table>
<thead>
<tr>
<th>Data Products</th>
<th>Data Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neutral Atmosphere</strong></td>
<td></td>
</tr>
<tr>
<td>- Bending angle profile</td>
<td>- Number of Profiles per day: 8000 [Threshold ]</td>
</tr>
<tr>
<td>- Refractivity profile</td>
<td>- Vertical Resolution:</td>
</tr>
<tr>
<td>- Temperature profile</td>
<td>- 0-25km: 0.1 km</td>
</tr>
<tr>
<td>- Water vapor profile</td>
<td>- 25-60km: 1.0 km</td>
</tr>
<tr>
<td></td>
<td>- Average Latency: 45 minutes [TBR]</td>
</tr>
<tr>
<td><strong>Ionosphere and Space Weather</strong></td>
<td></td>
</tr>
<tr>
<td>- Total Electron Content (TEC)</td>
<td>- Number of Profiles per day (TEC and EDP): 12000 [Threshold ]</td>
</tr>
<tr>
<td>- Electron Density Profile (EDP)</td>
<td>- Average Latency: 45 minutes</td>
</tr>
<tr>
<td>- Scintillation amplitude index (S_4)</td>
<td></td>
</tr>
<tr>
<td>- Scintillation phase index (S_f)</td>
<td></td>
</tr>
<tr>
<td><strong>Metadata</strong></td>
<td></td>
</tr>
<tr>
<td>- GNSS &amp; LEO satellite orbit location files</td>
<td></td>
</tr>
<tr>
<td>- Excess phase files</td>
<td></td>
</tr>
<tr>
<td>- Occultation tables</td>
<td></td>
</tr>
<tr>
<td>- Records of major processing algorithm revisions</td>
<td></td>
</tr>
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</table>
### System Implementation (1/2)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spacecraft Bus</strong></td>
<td>Attitude Control, Power Control, Thermal Control, Propulsion, Command and Data Handling, Flight Software, Structure</td>
</tr>
<tr>
<td><strong>Mission Payload</strong></td>
<td>TGRS (TriG GNSS Radio occultation System),</td>
</tr>
<tr>
<td><strong>Science Payload</strong></td>
<td></td>
</tr>
<tr>
<td>1\textsuperscript{st} Launch (U.S. Contribute)</td>
<td>2\textsuperscript{nd} Launch (Taiwan Contribute)</td>
</tr>
<tr>
<td>➢ IVM (Ion Velocity Meter)</td>
<td>➢ Will be acquired from Taiwan domestic universities or research centers.</td>
</tr>
<tr>
<td>➢ RF beacon (Radio Frequency Beacon scintillation instrument)</td>
<td>➢ Science payload interfaces shall be compatible with the ones of the 1\textsuperscript{st} launch.</td>
</tr>
<tr>
<td>➢ LRR (Laser Retro-Reflector)</td>
<td>➢ A science mission compatible with 1\textsuperscript{st} Launch is preferred.</td>
</tr>
</tbody>
</table>

IROWG-4 Melbourne, 16~22 April 2015
## System Implementation (2/2)

<table>
<thead>
<tr>
<th>Constellation</th>
<th>System</th>
</tr>
</thead>
</table>
| **First Launch (IOC)** | ◆ In Production: Mission Payload, Science Payload, Spacecraft Bus  
◆ USAF Contract: SpaceX Falcon Heavy for STP-2 Mission  
◆ In Development: U.S / Taiwan Data Processing Center  
◆ In Planning: Ground Stations  
◆ Target Launch Schedule: May 2016 *(to be announced in May 2015)* |
| **Second Launch (FOC)** | ◆ Pending on the commitments of mission payload and launch vehicle ride to activate the spacecraft bus and science payload acquisition.  
◆ Current Target Launch Schedule: 2018 *(the earliest)* |
FORMOSAT-7 / COSMIC-2 Major Program Milestones
May-2010: Taiwan & U.S. signed the collaboration agreement for this Joint Mission

May-2010: Conducted Feasibility Design Review (FDR) Meeting in Taiwan

Aug-2010: Joint Team Conducted Mission Definition Review (MDR) Meeting in Taiwan

Jan-2011: JPL conducted TriG PDR (Preliminary Design Review)

Apr-2011: Conducted the 1st ESC (Executive Steering Committee) Meeting in Taiwan

Apr-2011: Conducted System Design Review (SDR) Meeting in Taiwan

Nov-2011: NSPO ceased the 1st Spacecraft Bus procurement bid (< 3 bidders)

Dec-2011: Conducted the 2nd ESC Meeting in Taiwan (U.S Congress denied COSMIC-2 funding)

Feb-2012: Conducted the 3rd ESC Meeting in Taiwan

Aug-2012: NSPO awarded the Spacecraft contract for the 1st Launch set to SSTL-U.K.

Nov-2012: NSPO conducted the SSTL Spacecraft SDR (System Design Review) in Taiwan

Dec-2012: USAF awarded an L/V contract to SpaceX Falcon Heavy for the 1st Launch

Dec-2012: Taiwan & U.S. signed the IA#1 (Implementing Arrangement #1)
FORMOSAT-7 / COSMIC-2 Accomplished & Planned Major Milestones (2/2)

- Jan-2013: Conducted the 4\textsuperscript{th} ESC Meeting in the U.S. \textit{(Continuing Resolution Issue)}
- Jun-2013: NSPO conducted Spacecraft PDR (Preliminary Design Review) at SSTL U.K.
- Jun-2013: Conducted Joint Program PDR-A at SSTL U.K.
- Nov-2013: NSPO conducted Spacecraft CDR (Critical Design Review) at NSPO Taiwan
- Dec-2013: Joint Team Conducted Joint Program PDR-B at NSPO
- Jun-2014: NSPO conducted Spacecraft ITR (I&T Readiness) Review at SSTL U.K.
- Dec-2014: SSTL completed PFM I&T at SSTL U.K.
- Mar-2015: FAR & SSTL delivers the PFM (Proto-Flight Model) and FM2 to NSPO
- Mar-2015: NSPO begins FM2~FM6 I&T at NSPO I&T Facility
- May-2015: SSTL delivers FM3~FM6 Kits to NSPO I&T Facility
- Mar-2016: NSPO delivers FM1~6 to Cap Canaveral and begins the launch campaign
- May-2016: Space-X conducts STP-2 Launch (FORMOSAT-7 / COSMIC-2 1\textsuperscript{st} Launch)
- May-2016: NSPO conducts LEOP Check-Out and FM1~FM6 Constellation Deployments
Spacecraft Bus Developments
~ 223 Kg each S/C (including shared portion of the MSD*)

* Note: MSD - Multiple Satellites Dispenser
SSTL Original RFP Spacecraft Bus Configuration

August 2012

~217 Kg each S/C
~ 41.6 Kg one MSD
SSTL Original RFP Spacecraft Bus fit inside MINOTAUR-IV L/V

August 2012

~217 Kg each S/C
~ 41.6 Kg one MSD
SSTL Spacecraft Bus Configuration at System Design Review (1/2)

November 2012

~204 Kg each S/C
~118 Kg one MSD
SSTL Spacecraft Bus Configuration at System Design Review

November 2012

~204 Kg each S/C
~ 118 Kg one MSD
w/o margin

Courtesy of SSTL from Spacecraft Bus SDR
The decision was jointly made in January 2013 to incorporate the MSD with ESPA Grande Ring for a better acquisition strategy for placing the launch vehicles for both Launches.
SSTL Spacecraft Bus Configuration to fit ESPA on Falcon Heavy L/V

ESPAGrande Ring

January 2013

~285.4 Kg* each S/C
Using ESPA as MSD

* Note: 256.3 Kg w/o 5% margin

Conceptual Design of SSTL’s Spacecraft
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Requirements</th>
</tr>
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<tbody>
<tr>
<td>Dimensions (stowed)</td>
<td>1000 x 1250 x 1250 mm</td>
</tr>
<tr>
<td>Launch Mass (wet)</td>
<td>277.8 kg</td>
</tr>
<tr>
<td>Platform Power Required</td>
<td>229.8 W (orbit average)</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>&gt; 22.5A-hr</td>
</tr>
<tr>
<td>Attitude</td>
<td>3-Axis; Knowledge &lt; 0.07deg (3-sigma); Control &lt; 1deg (3-sigma)</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Hydrazine monoprop ~141 m/s</td>
</tr>
<tr>
<td>Communications</td>
<td>S-band TM/TC, 32kbps Uplink, up to 2Mbps Downlink</td>
</tr>
<tr>
<td>Navigation</td>
<td>GPS</td>
</tr>
<tr>
<td>Design Life</td>
<td>5 years, &gt;66%</td>
</tr>
<tr>
<td>Availability</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Launch Compatibility</td>
<td>EELV (ESPA Grande Adapter)</td>
</tr>
<tr>
<td>Payload support</td>
<td>&gt; 2Gbits Data Storage; 39.4kg mass; 95W OAP</td>
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</tbody>
</table>
SSTL Spacecraft Bus Configuration as Designed (1/2)
SSTL Spacecraft Bus Configuration as Designed (2/2)

- SC ACTIVATION SWITCHES
- THRUSTERS x 2
- SEPARATION SYS PASSIVE RING
- RX ANTENNA x 2
- LOW RATE TX ANTENNA
- UMBILICAL BREAKAWAY CONNECTOR x 2
- TGRS POD +X
- TGRS RO +X
- +Xsc DIRECTION OF FLIGHT
- IVM
- +Zsc NADIR DIRECTION
- SOLAR ARRAY
- SOLAR ARRAY DRIVE MECHANISM
- HOLD DOWN RELEASE SYSTEM x 4
- SUN SENSOR x 2
- GPS ANTENNA x 2
SSTL Spacecraft Bus Stowed Configuration
TGRS Mission Payload Developments
The TGRS is a Global Navigation Satellite System (GNSS) science instrument for low Earth orbit. The TGRS consists of one FM TriG receiver, two Precise Orbit Determination (POD) antennas, two Radio Occultation (RO) antennas, eight Low Noise Amplifier (LNA)/Filter Assemblies for each antenna input and 16 RF cables. The TGRS is capable of tracking signals from GPS and GLONASS. It can measure the phase and group delay of the signals for orbit determination and radio occultation studies/application.
TGRS EM System Level Outdoor Testing

Outdoor System Testing

RO Subarrays

PODs 2-ring choke

SNRv

RF2
RF4
RF1
RF3

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## TGRS Neutral Atmosphere Product Requirements

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Profiles per day</td>
<td>1100</td>
<td>1100</td>
</tr>
<tr>
<td>Vertical Data Resolution [km]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Altitude Range 0 - 25 km MSL</td>
<td>a. 0.1</td>
<td>a. 0.1</td>
</tr>
<tr>
<td>b. Altitude Range 25 - 60 km MSL</td>
<td>b. 1.5</td>
<td>b. 1.5</td>
</tr>
<tr>
<td>Measurement Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Bending Angle [μrad]</td>
<td>a. 0 - 120,000</td>
<td>a. 0 - 150,000</td>
</tr>
<tr>
<td>b. Refractivity [Refractivity-N units]</td>
<td>b. 0 – 500</td>
<td>b. 0 – 500</td>
</tr>
<tr>
<td>RMS Measurement Uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Bending Angle (0 – 10 km) [%]</td>
<td>a. 3</td>
<td>a. 3</td>
</tr>
<tr>
<td>b. Bending Angle (10 – 20 km) [%]</td>
<td>b. 0.7</td>
<td>b. 0.7</td>
</tr>
<tr>
<td>c. Bending Angle (20 - 60 km) [μrad]</td>
<td>c. 1.5</td>
<td>c. 1.5</td>
</tr>
<tr>
<td>d. Refractivity (0 - 10 km) [%]</td>
<td>d. 0.4</td>
<td>d. 0.4</td>
</tr>
<tr>
<td>e. Refractivity (10 - 20 km) [%]</td>
<td>e. 0.1</td>
<td>e. 0.1</td>
</tr>
<tr>
<td>f. Refractivity (20 - 30 km) [%]</td>
<td>f. 0.3</td>
<td>f. 0.3</td>
</tr>
<tr>
<td>RMS Measurement Uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Bending Angle (10 - 60 km) [μrad]</td>
<td>a. 0.36</td>
<td>a. 0.18</td>
</tr>
<tr>
<td>b. Refractivity (30 km) [%]</td>
<td>b. 0.076</td>
<td>b. 0.038</td>
</tr>
<tr>
<td>c. Bending Angle (10 - 60 km) [μrad]</td>
<td>c. 0.78</td>
<td>c. 0.39</td>
</tr>
<tr>
<td>d. Refractivity (30 km) [%]</td>
<td>d. 0.16</td>
<td>d. 0.08</td>
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<tr>
<td>Systematic Measurement Uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Bending Angle (0 - 60 km) [μrad]</td>
<td>a. 0.05</td>
<td>a. 0.016</td>
</tr>
<tr>
<td>b. Refractivity (30 km) [%]</td>
<td>b. 0.04</td>
<td>b. 0.013</td>
</tr>
</tbody>
</table>

Note: This number represents 90% of all possible neutral atmospheric occultations observable from either the low or high inclination COSMIC-2 orbits that are associated with the currently operational GPS (31 satellites) and GLONASS (24 satellites) constellations. Neutral atmospheric occultations are defined to be occultations that occur within ±55° of the LEO spacecraft velocity or anti-velocity vector.
## TGRS Ionosphere Product Requirements

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Type</strong></td>
<td><strong>Threshold</strong></td>
</tr>
<tr>
<td><strong>TEC Measurement Range [TECu]</strong> &lt;TEC is measured in TEC units (TECu) = 1016 electrons/m2&gt;</td>
<td>0 to 2,000</td>
</tr>
<tr>
<td>Systematic Measurement Error</td>
<td></td>
</tr>
<tr>
<td>a. Relative [TECu]</td>
<td>0.3</td>
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<tr>
<td>b. Absolute [TECu]</td>
<td>3</td>
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<tr>
<td>Number of Limb TEC Profiles per day</td>
<td>1015</td>
</tr>
<tr>
<td>Number of Zenith hemisphere TEC tracks/day (each TEC arc is expected to be in two tracks corresponding to the TGRS fore and aft POD antennas)</td>
<td>1015</td>
</tr>
<tr>
<td>TEC sampling rate [seconds]</td>
<td></td>
</tr>
<tr>
<td>a. Occulting satellites</td>
<td>1</td>
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<tr>
<td>b. Zenith Hemisphere Satellites</td>
<td>10</td>
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<tr>
<td>Measurement Range</td>
<td></td>
</tr>
<tr>
<td>a. S4 [dimensionless]</td>
<td>0.1 to 1.5</td>
</tr>
<tr>
<td>b. σφ [radians]</td>
<td>0.1 to 3.14</td>
</tr>
<tr>
<td>RMS Measurement Uncertainty</td>
<td></td>
</tr>
<tr>
<td>a. S4 [dimensionless]</td>
<td>0.1</td>
</tr>
<tr>
<td>b. σφ [radians]</td>
<td>0.1</td>
</tr>
<tr>
<td>GNSS Frequencies for S4/σφ Calculations</td>
<td>L1/L2</td>
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<tr>
<td><strong>S4/σφ Underlying Minimum Sample Rate [Hz]</strong></td>
<td>50</td>
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<tr>
<td><strong>S4/σφ Calculation Time Interval [seconds]</strong></td>
<td>10</td>
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<tr>
<td><strong>S4/σφ Calculation Cadence [seconds]</strong></td>
<td>10</td>
</tr>
<tr>
<td>Tracks Analyzed for S4/σφ Calculations</td>
<td>All</td>
</tr>
<tr>
<td>Ionospheric Occultation High Rate Data Sent to Ground (60 km to S/C Altitude)</td>
<td>Strongly scintillated profiles up to 10% of sensor data budget</td>
</tr>
<tr>
<td><strong>Ionospheric Tangent Altitude Range [km]</strong></td>
<td>60 – S/C Altitude</td>
</tr>
</tbody>
</table>
Payload Field of Views (FOV) for Analysis

POD

RF Beacon

OCC
FORMOSAT-7 / COSMIC-2 Current Satellite Production Status
FORMOSAT-7/COSCIMIC-2 PFM Testing at British Aerospace in Stevenage, U.K.

EMC / EMI Testing in Anechoic Chamber (Nov. 2014)

Dynamic Testing on Vibration Shaker (Dec. 2014)
FORMOSAT-7/COSMIC-2 PFM Testing
Separation System Test at SSTL U.K.

Satellite-to-Launch Vehicle Adaptor Clampband Separation System Test (Dec. 2014)

Before

After

Courtesy of SSTL
PFM Solar Array Undergoing Deployment Test at SSTL U.K.

(Nov. 2014)
PFM and FM3 Ready for Packing to Ship in U.K. SSTL High-Bay

(Mar. 2015)
PFM / FM3 & GSE Arrival at NSPO I&T Facilities (March 26, 2015)
PFM and FM3 Unpacking at NSPO I&T High-Bay
NSPO Director General Chang, et. al Thumb-Up to the PFM & FM3 Receiving
Setting Up GSE and SSTL / NSPO I&T On-Site Training
Status of the Remaining FM Production at SSTL U.K.

FM2 - Software and SKED Development Test Bed

FM4 - Structure & Harness Checked Out and Integrated

FM5 - ‘H’ Frame Structure Completed

FM6 – Just Received Structural Panels no Assembly Photo
SSTL Spacecraft Bus Schedule Overview

2013
- WSD
- SDR
- Pre PDR
- PDR

2014
- CDR
- ITR#1

2015
- FAR
- A1
- A2

Requirements
- PL Sim
- PL #1
- U.S. Payload
- PL #2-6

Verification planning

Verification

Initial Design
- Detailed Design
- Developments

Procurement

Manufacture Heritage

Manufacture new builds

I&T Planning
- Harness, EGSE, MGSE

I&T SC1
- PL I&T
- EVT
- I&T SC 2-6

IROWG-4 Melbourne, 16~22 April 2015
Launch System Developments
NSPO will ship all six satellites to Cap Canaveral in March 2016 to begin the launch campaign.
All STP-2 Satellite Preparation for Launch

STP-2 Primary Passenger:
FORMOSAT-7 / COSMIC-2

STP-2 Co-Passengers:
DSX;
FalconSat-6;
GPIM;
OTB;
NPSAT-1;
Oculus;
Prox-1
Planned Launch Site: SpaceX Launch Pad LC-39A

STP-2 Launch Vehicle: SpaceX Falcon Heavy


Falcon Heavy from LC-39A CCAFS

IROWG-4 Melbourne, 16~22 April 2015
Satellite Constellation Deployment
FORMOSAT-7 / COSMIC-2 Mission Architecture

GALILEO or GLONASS-FDMA

NSPO-Built S/C

FORMOSAT-7/COSMIC-2

TT&C stations (Taiwan)

TT&C stations (overseas)

Fiducial Network

US DPC

Taiwan DPC

Launch Vehicles

Satellite Operations and Control Center

Users

Researchers

High-inc

Low-inc

GPS
Artistic FORMOSAT-7 / COSMIC-2 Satellite Illustration in Orbit
Constellation Deployment Maneuver Time
IOC Deployed Constellation for the 1st Launch
Ground System Developments
FORMOSAT-7 / COSMIC-2 Ground Communication Networks
- Achieving 45 Minutes Data Latency -

72° Orbit Data Recovery
Current FORMOSAT-3 / COSMIC Network

- KSAT Tromso
- KSAT Troll (Back Up)
- NOAA FCDAS
- NASA McMurdo

24° Orbit Data Recovery
FORMOSAT-7 / COSMIC-2 Candidate Sites

Potential Low-Mid Latitude Candidate Sites:
- Florida, Hawaii, Guam U.S.A.
- Honduras
- Singapore
- Maritus
- Bahir Dar, Ethiopia
- Darwin (Bureau of Meteorology), Australia
- Cuiabá (IPNE), Brazil
- Taiwan

Courtesy of NOAA
## FORMOSAT-7 / COSMIC-2 Equatorial Ground Stations Status

<table>
<thead>
<tr>
<th>Ground Station Location</th>
<th>Partner / Sponsor</th>
<th>Level of Commitment</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan</td>
<td>NSPO</td>
<td>100%</td>
<td>Uses existing Capability</td>
</tr>
<tr>
<td>Cuiaba, Brazil</td>
<td>INPE</td>
<td>100%</td>
<td>INPE awarded contract for GS in Jan 2014, MOU with NOAA in final Coordination</td>
</tr>
<tr>
<td>Mark IV-B – Hawaii</td>
<td>USAF</td>
<td>100%</td>
<td>Working with USAF to establish compatibility with COSMIC-2 downlink</td>
</tr>
<tr>
<td>Mark IV-B – Guam</td>
<td>USAF</td>
<td>100%</td>
<td>Working with USAF to establish compatibility with COSMIC-2 downlink</td>
</tr>
<tr>
<td>Mark IV-B – Honduras</td>
<td>USAF</td>
<td>100%</td>
<td>Working with USAF to establish compatibility with COSMIC-2 downlink</td>
</tr>
<tr>
<td>Darwin, Australia</td>
<td>BoM</td>
<td>~90%</td>
<td>BoM Australia discussing path forward to provide dedicated support</td>
</tr>
<tr>
<td>North Africa (TBD)</td>
<td>Commercial Service</td>
<td>0%</td>
<td>Subject of a FY15 solicitation for Data Services from commercial providers</td>
</tr>
<tr>
<td>Mauritius (TBD)</td>
<td>Commercial Service</td>
<td>0%</td>
<td>Subject of a FY15 solicitation for Data Services from commercial providers</td>
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</table>
# Data Latency vs. Potentially Planned RTS Network

<table>
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<tr>
<th>LEO Inc. (deg)</th>
<th>RTS Network</th>
<th>Average Latency (min)</th>
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<tr>
<td>24</td>
<td>Taiwan, Darwin, Cuiaba, Mauritius, BahirDar</td>
<td>36.9</td>
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<tr>
<td>24</td>
<td>Taiwan, Darwin, Cuiaba, Mauritius, BahirDar, + Dedicated Guam, Hawaii, Honduras</td>
<td>26.9</td>
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<tr>
<td>24</td>
<td>Taiwan, Darwin, Cuiaba, Mauritius, BahirDar, + Shared Guam, Hawaii, Honduras</td>
<td>29.7</td>
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<tr>
<td>72</td>
<td>Fairbanks, Tromso, McMurdo, TrollSat</td>
<td>35.0</td>
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<tr>
<td>72</td>
<td>Fairbanks, Tromso, McMurdo, TrollSat + Taiwan, Darwin, Cuiaba, Mauritius, BahirDar</td>
<td>29.2</td>
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</tbody>
</table>
Joint Program Master Schedule

&

Mission Data Policy
FORMOSAT-7 / COSMIC-2 Integrated Master Schedule

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<td>IMS Program Milestone Reviews</td>
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<td>1.0 Program Management</td>
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<td>3.0 Mission Assurance</td>
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<td>4.0 Satellite Procurement</td>
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<td>TGRS Mission Payload</td>
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<td>Science Payload (Taiwan)</td>
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<td>NSPO-Built Satellite</td>
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<td>5.0 Launch</td>
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<td>6.0 Ground and Mission Ops</td>
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<td>7.0 Data Processing</td>
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<td>8.0 Data Utilization</td>
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</tbody>
</table>

Date: 31 March 2015

FS-7/C-2 Integrated Master Schedule
Quick Update on the 2nd Launch Implementation

- **May-2010:** Taiwan & U.S. signed the collaboration agreement for this Joint Mission
- **Dec-2011:** Conducted the 2nd ESC Meeting in Taiwan (U.S Congress denied COSMIC-2 funding)
- **Aug-2012:** NSPO awarded the Spacecraft contract for the 1st Launch set to SSTL-U.K.
- **Dec-2012:** USAF awarded an L/V contract to SpaceX Falcon Heavy for the 1st Launch
- **Dec-2012:** Taiwan & U.S. signed the IA#1 (Implementing Arrangement #1)
- **Jan-2013:** Conducted the 4th ESC Meeting in the U.S. (Continuing Resolution Issue)
- **Feb-2014:** U.S. Congress approved and allocated fund for COSMIC-2 as a new Program
- **Nov-2014:** Conducted the 6th ESC Meeting in Taiwan to conclude to move forward with the 2nd Launch
- **Feb-2015:** NOAA requested FY 2016 President Budget of U.S. $ 9.9 M for COSMIC-2 toward the 2nd Launch has been submitted
- **Mar-2015:** Amendment No.1 to the IA#1 through AIT/TECRO to update from 6-Satellite/1-Launch to 12-Satellite/2-Launch has been in work
FORMOSAT-7 / COSMIC-2 Major Collaboration Partners

- **U.S.A.**
  - NOAA
  - Department of Commerce
  - JPL
  - UCAR
  - NSF
  - NASA
  - SpaceX
  - SRI International
  - MOOG
  -UTD
  - AEROSPACE
  - Ball

- **Taiwan**
  - NSPO
  - NAR Labs
  - Academia Sinica
  - Ministry of Science and Technology

- **Europe**
  - Surrey Satellite Technology LTD

- **Australia**
  - Australian Government Bureau of Meteorology
Adapting Free and Open Data Policy

Following FORMOSAT-3/COSMIC, FORMOSAT-7/COSMIC-2, another major Taiwan/U.S. Joint Mission, will adapt the free and open data policy to provide the global data users with the near real-time and the archived radio occultation data for weather, climate, ionosphere, geo-science researches and non-commercial weather forecast prediction.
TDPC / USDPC will distribute the near-real-time GPS/GLONOSS RO neutral atmospheric data products (i.e. vertical profiles of bending angles, refractivity, electron density, temperature, pressure, and water vapor in the atmosphere) immediately after processing in WMO-approved BUFR (Binary Universal Form for the Representation) format to NOAA’s NESDIS (National Environmental Satellite, Data, and Information Service), which will then distribute these products via the GTS (Global Telecommunication System) to the international weather centers.

The distribution and the data format of the near-real-time GPS/GLONSS ionospheric data products from the TGRS Payload are under evaluation.
The IVM and RF Beacon Data and Data Products will be distributed by the U.S. Air Force by means of the FORMOSAT-7 / COSMIC-2 Science Data Use Agreement. <under discussion>

The related Satellite Bus telemetry data for the Data Users may be released at NSPO’s discretion. <under discussion>

Soliciting YOUR input for other beneficiary Data Distribution Policy!
FORMOSAT-3 / COSMIC-1 ➔ FORMOSAT-7 / COSMIC-2

IROWG-4 Melbourne, 16~22 April 2015
The 3rd International Conference on GPS Radio Occultation (ICGPSRO 2016)

Time:
- March 9 (Wednesday) ~ 11 (Friday), 2016

Venue:
- Howard International House, Taipei, Taiwan
Conclusion
As the world’s first GPSRO constellation, FORMOSAT-3/COSMIC has clearly demonstrated the advantages and utilities of a GPS RO constellation and has fulfilled all the promises and more.

The contribution of FORMOSAT-3 / COSMIC GPSRO Constellation system to improve weather prediction and promote new ionospheric observations is “significant” and represents an immense benefit to worldwide forecasting capability.

Constellation Radio Occultation Measurement has become a powerful Earth Observation System. NSPO and NOAA have recognized the need and the opportunity and jointly implemented a next generation GPSRO Constellation, i.e. FORMOSAT-7 / COSMIC-2 mission, with greater global coverage. The Initial Operational Capability (IOC) is targeted for 2016.

It is certain that the implementation and realization of FORMOSAT-7 / COSMIC-2 GPSRO Constellation system will further increase weather forecast and monitoring capabilities in this unique Earth observation mission.
Thank You!